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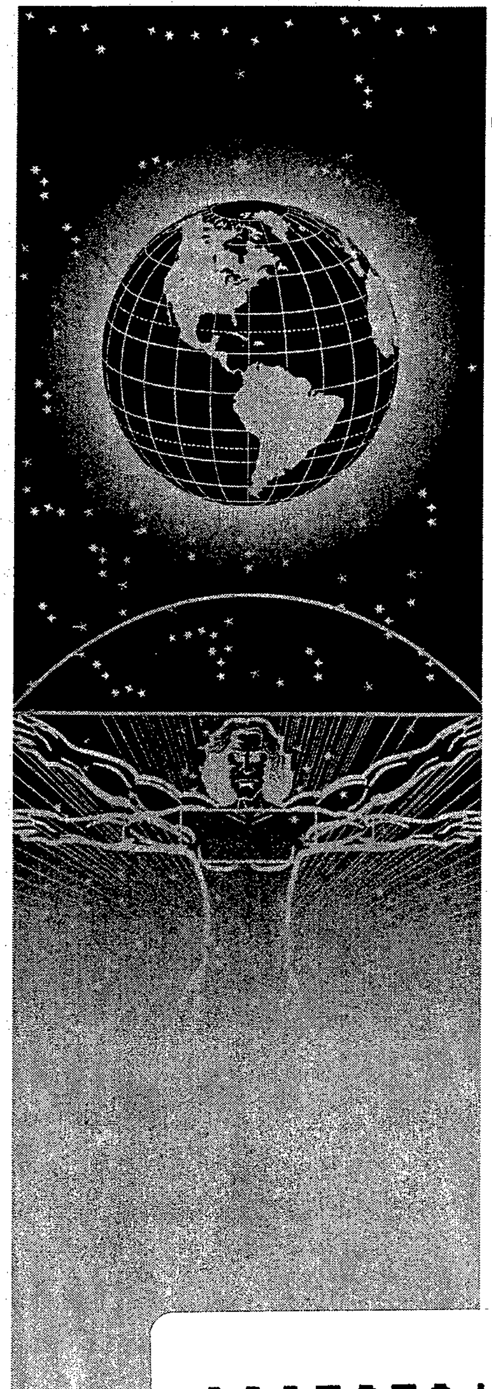

UNITED STATES AIR FORCE RESEARCH LABORATORY

A STATISTICAL ANALYSIS OF THE SIZING SYSTEM FOR THE ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS)

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Approved for public release; distribution is unlimited

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2002-0174

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

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The current Anti-G suite sizing system appears adequate for the male target population. It covers approximately 98.5% of that population. Three sizes are found to be candidates for elimination from the system: Sizes 7, 3, and 8. Several opportunities exist for system improvement by reproportioning some sizes. Recommendations were made for reproportioning sizes for men.

Waist Circumference (at Iliocristable) and Crotch Height were identified as the key anthropometric dimensions for distinguishing suit sizes. The procurement tariff resulting from this analysis differs significantly from that projected based on design criteria.

Female data were collected in conjunction with the men, but analyzed and reported separately. It was clear that large proportional differences in the waist versus the hip made the suits unacceptable for many women. It was apparent that this type of Anti-G suit required sizes specifically proportioned for the female form. Past studies indicate that source of the problem, and the female data analysis includes results and comparisons from other studies. Size recommendations for women were made based on that analysis.

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PREFACE

This study was conducted under contracts F33615-89-C-0572 and F41624-93-C-6001 with Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. The authors wish to thank Master Sergeant Durrell Bess and Staff Sergeant Kent Lewis of the Crew Technology Division at Brooks Air Force Base, and Ms. Sherri Blackwell and Mr. Henry Case of Anthropology Research Project, Inc. for their expertise in anthropometry and their outstanding efforts in planning and conducting data collection. The authors also wish to thank Mrs. Stacie Taylor and Mr. Patrick Files of Sytronics, Inc. for preparing numerous graphics and providing editorial support.

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EXECUTIVE SUMMARY

The Advanced Technology Anti-G Suit (ATAGS) is an extended-cover anti-G garment designed to replace the standard U.S. Air Force G-suit, the CSU-13B/P. A fit test of the ATAGS was conducted by investigators from the Human Engineering and the Crew Technology divisions at Armstrong Laboratory. The objectives were to assess the anthropometric sizing issues as they pertain to the Air Force male and female aircrew population currently flying, or expecting assignment to, fighter aircraft.

Results indicate that the current anti-G suit sizing system is adequate for the male target population. It covers approximately 98.5% of that population, as is. However, some recommendations can be made to improve the fit of the patterns. Furthermore, it appears that three sizes could be eliminated with an expected population coverage drop to 94%. Waist Circumference (at Iliocristale) and Crotch Height were identified as the key anthropometric dimensions for distinguishing suit size. A new size selection chart and procurement tariff were developed.

Five active-duty female pilots who had experience with anti-G suits were tested in the ATAGS. With only five subjects, our analytical approach was to determine expected relevant gender-proportional differences, make inferences about the ATAGS females based on other studies, and make recommendations regarding an ATAGS sizing system that will accommodate women. It was clear from the females studied that large proportional differences in the waist versus the hip made the suits unacceptable for many women. It was apparent that this type of anti-G suit requires sizes specifically proportioned for a female form. Past studies validate this conclusion.

A complete set of six female-proportioned sizes are recommended in the event that pilot training entrance requirements are changed to permit entry of more females. Four of these sizes are needed to accommodate the current female pilot population. It is also recommended that more lacing cord be added to the adjustment laces in the waist area of the women's sizes to allow a better fit in the waist-to-hip region. The recommended women's sizes should be prototyped and fit tested in order to determine whether the sizing system described in this report is adequate.

INTRODUCTION

Anthropometric sizing is necessary in the design of clothing and personal protective equipment for several reasons, which are the objectives of this study.

Objectives of ATAGS Fit Analysis
• To determine who fits in what size. • To determine how many of which size are needed to fit the aircrew population (i.e., the procurement tariff). • To determine if all of the available sizes are necessary. • To determine if all sizes needed are available. • To determine if any changes to the patterns are necessary.

Sizing becomes more critical when a design item must accommodate a large, diverse user population.

Fit tests conducted on protective equipment ranging from body armor (Zehner et al., 1987) to flight helmets (Blackwell and Robinette, 1993) indicate that, regardless of who the item is "designed" or intended to fit, the body size and shape it fits, the quality of fit, and the range of fit cannot be determined until a prototype is tested. The fit of an item is inseparably linked to design; knowledge of anthropometry alone is not adequate for determining fit. Therefore, a fit relationship to the anthropometry for a particular design must be defined in order to determine the optimum number, assortment, and proportioning of sizes.

For example, during evaluation of uniforms for U.S. Navy women (Mellian et al., 1991, and Robinette et al., 1991) investigators discovered that many of the neighboring size patterns were so similar that in reality the patterns were exactly the same! Each size pattern was designed to fit different sizes, but in fact, they did not. Furthermore, the full set of sizes did not fit a large segment of the population of women who had a certain type of body proportion. These were women who had comparable waist and bust sizes to existing sizes, but larger hips at those waist and bust sizes. This proportion type was later dubbed "women's."

For most items it is not anticipated that the true overlap would be as significant as in the above example. However, until a prototype is tested it is impossible to determine how wide the range of fit is for a single size, and subsequently, how much overlap (if any) there is among the different sizes. This need for prototype testing was exemplified during fit tests of three independently manufactured aircrew helmets. All helmets were designed to be a size "large." Although there were a few cases where a person achieved an acceptable fit in all three helmets, the results more often revealed that a person received an acceptable fit in one helmet but not the others. The optimal fit for each helmet occurred for different head and face proportions. In addition, the ranges of fit were different for each of the three helmets.

In summer 1993, a team of investigators from the Human Engineering and the Crew Technology divisions at Armstrong Laboratory conducted a fit evaluation of the Advanced Technology Anti-G Suit (ATAGS). ATAGS is an extended-cover anti-G garment designed to replace the standard U.S. Air Force G-Suit, the CSU-13B/P. The objectives of the evaluation were to assess the four anthropometric sizing issues as they pertain to the Air Force aircrew population currently flying, or expecting assignment to, fighter aircraft.

Once validated, the sizing system must be effectively implemented. To implement the sizing system, we need to define a size selection chart. For a size selection chart, we must identify the set of two anthropometric dimensions that best distinguish between the sizes. No set of just two dimensions will distinguish between the sizes perfectly, but they can nonetheless serve as reasonable guidelines for selecting the best-fitting size.

Finally, the Air Force must have some idea of what percentages of the target population need to be accommodated by the different suit sizes, so that they can purchase appropriate quantities of each size.

BACKGROUND

The data for this analysis falls into two principal categories: Data about the anti-G suit itself and the way in which it fits, and data about the personnel wearing the suit. Both must be considered in evaluating the quality of fit and in considering what adjustments, if any, need to be made to the suit design to improve the quality of fit.

Suit data consists primarily of specifications for suit size and definitions of the ratings used for characterizing the suit fit. Although researchers collected a great deal of information on suit sizing related to subsidiary measurements of anthropometric dimensions, that information was not applied in this analysis, and so is not included here.

The anti-G suit sizing system specifies nine different sizes. These sizes are based upon two key anthropometric dimensions: Waist Circumference (at omphalion) and Waist Height (at omphalion). See Table 1.

Table 1. Anti-G Suit Size Specifications

Anti-G Suit Size Specifications			
Waist Height (omphalion)	**Waist Circumference (omphalion)**		
	28.5 in to 33 in	33 in to 37.5 in	37.5 in to 42 in
43.5 in to 46.5 in	Size 3	Size 6	Size 9
40.5 in to 43.5 in	Size 2	Size 5	Size 8
37.5 in to 40.5 in	Size 1	Size 4	Size 7

Fit Data

There were two different types of ratings on the suit fit: one that characterized the overall fit of the suit and one that characterized the fit for a particular garment area. Each type is described below.

Overall Fit Ratings

These ratings consisted simply of *Excellent, Good, Fair, Poor.* Any rating below *Good* was considered unacceptable. The codes for these ratings are as follows:

- Excellent: 1
- Good: 2
- Fair: 3
- Poor: 4

If a fit could not be evaluated because the waist was too large for the garment to stay up properly, the fit was assigned a code of 5.

Garment Area Fit Ratings

These ratings were applied to nine different garment areas:

- Waist
- Hip
- Knee
- Waist height
- Hip height
- Knee height
- Thigh length
- Lower leg
- Leg length

The ratings were used to characterize the fit in terms of *tight/loose* or *short/long.* Interpretation of the codings is depicted below:

Tight/Short	OK	Loose/Long
1	3	5

Personnel Data

In order to generalize the results of this study to the entire target population, we need to be sure that the sample is fairly representative of that population. Three relevant categories of population characteristics are job function, demographics, and anthropometric dimensions. Job function is relevant, because the aircrew personnel wearing the anti-G suit must be able to perform their assigned functions. Demographics are of interest, because the correlations among different anthropometric measurements can vary systematically with such variables as age or race.

These correlations are pertinent to suit design. The importance of anthropometric dimensions is clear.

Demographics

The data collected for this study comes from a sample of 270 U.S. Air Force aircrew personnel consisting of 265 males and 5 females. All subjects were experienced with anti-G suits. This was a pre-determined selection criteria, because experienced crew members provide the highest quality results. While five women may seem like a small number, it is in fact a good response. Female pilots are rare, since the stature and sitting height entry limits for pilots allow only approximately 25% of Air Force women to qualify for flight training. Female pilots with anti-G suit experience are more rare, since women have not as yet been assigned to combat roles. The charts and plots on the next several pages provide a detailed look at demographics.

The sample consisted of fighter pilots (112), pilot trainees (67), and Operations personnel (54). Over 98% of the subjects were white. Subject age is more uniformly distributed, the large majority of subjects being between 23 and 35 years old. The rank of over half the subjects (154) was Captain, with the other half being split in a ratio of about 2:1 between 2nd and 1st Lieutenants, respectively. See Tables 2, 3, and 4 and Figure 1.

The range of subjects appears good in that the subject weight, height, and waist measurements exhibit an approximate Normal distribution. The actual distribution is slightly skewed to the right, but this is to be expected in any statistical population that has a lower bound on the measured values. See Figures 2, 3, and 4.

Tables 5 through 9 show the frequency distributions for location, major command, race, age, and rank, respectively, for males and females.

Table 2. Distribution of Subject Specialty Codes

Specialty Code	Freq	Percent	Cum Freq	Cum Percent
00xx o Pilot Trainee	67	25.19	67	25.19
10xx o Ops: Helo, Airlift, Tanker	5	1.88	72	27.07
11xx o Pilot: Fighter/Jet	112	42.11	184	69.17
12xx o Pilot: Strategic Bomber	1	.38	185	69.55
13xx o Ops: Recon, EW, ABCC, IP	54	20.30	239	89.85
14xx o Ops: Staff	3	1.13	242	90.98
15xx o Navigator	14	5.26	256	96.24
22xx o Navigator	4	1.50	260	97.74
26xx o Scientific	1	.38	261	98.12
27xx o Acquisition Program Mgmt.	1	.38	262	98.50
28xx o Development Engineering	2	.75	264	99.25
78xx o Morale, Welfare, Rec. & Services	1	.38	265	99.62
80xx o Intelligence	1	.38	266	100.00

Table 3. Distribution of Subject Race

Rank	Frequency	Percent	Cumulative Frequency	Cumulative Percent
White	265	98.15	265	98.15
Black	4	1.48	269	99.63
Asian	1	.37	270	100.00

Table 4. Distribution of Subject Rank

Rank	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2nd Lieutenant	70	25.93	70	25.93
1st Lieutenant	37	13.70	107	39.63
Captain	154	57.04	261	96.67
Major	8	2.96	269	99.63
Lt. Colonel	1	.37	270	100.00

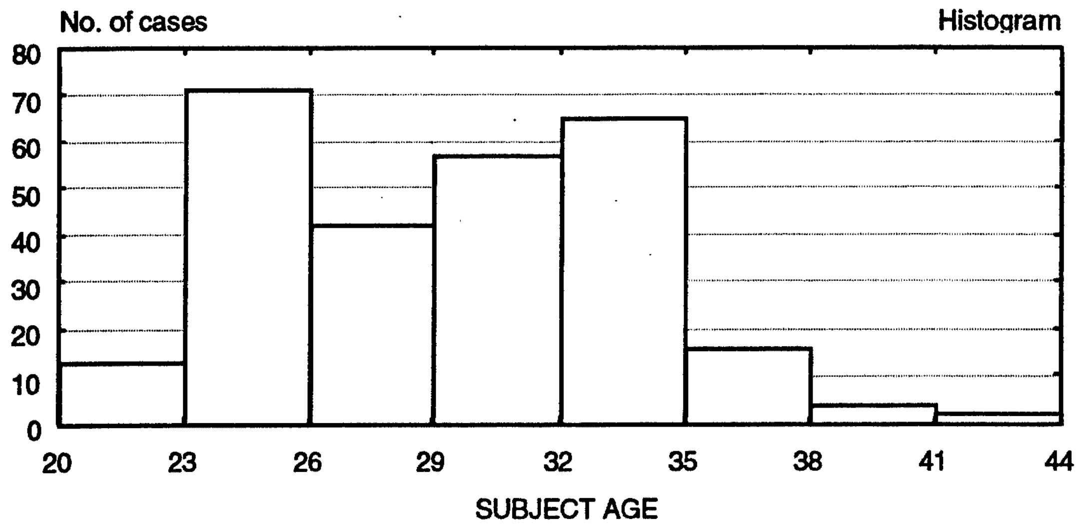

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Figure 1. Distribution of Subject Age

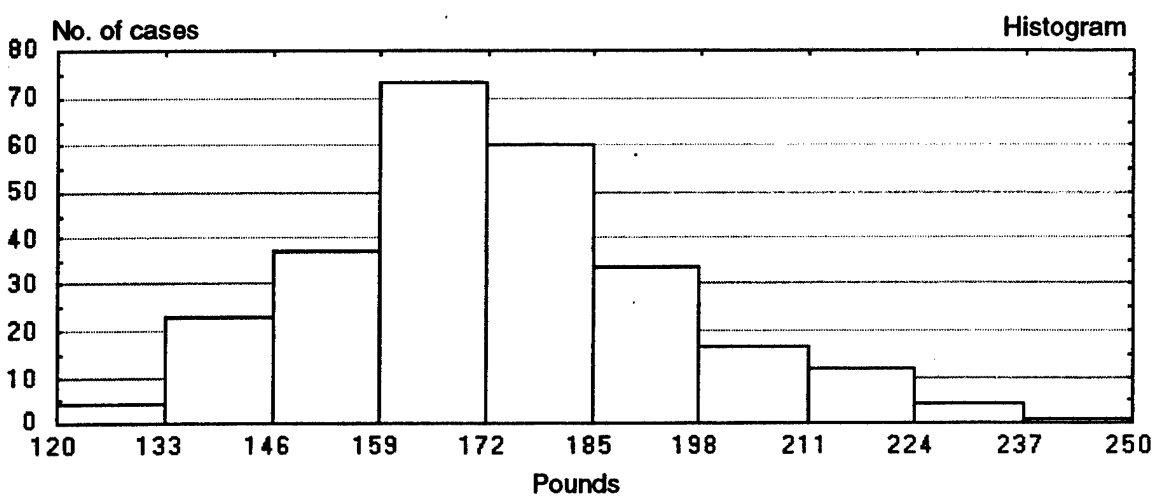

Figure 2. Distribution of Subject Weight

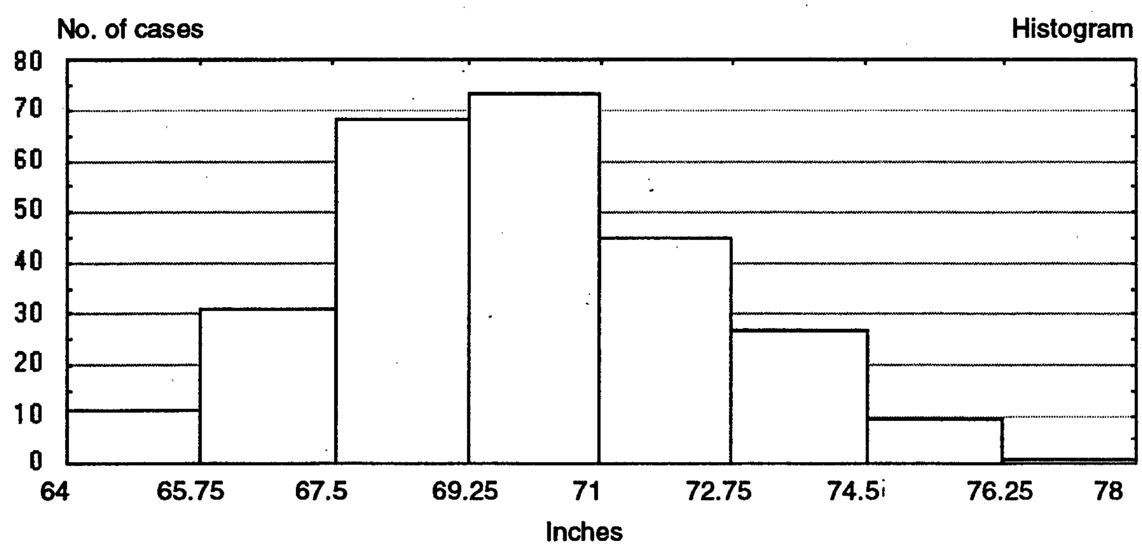

Figure 3. Distribution of Subject Height

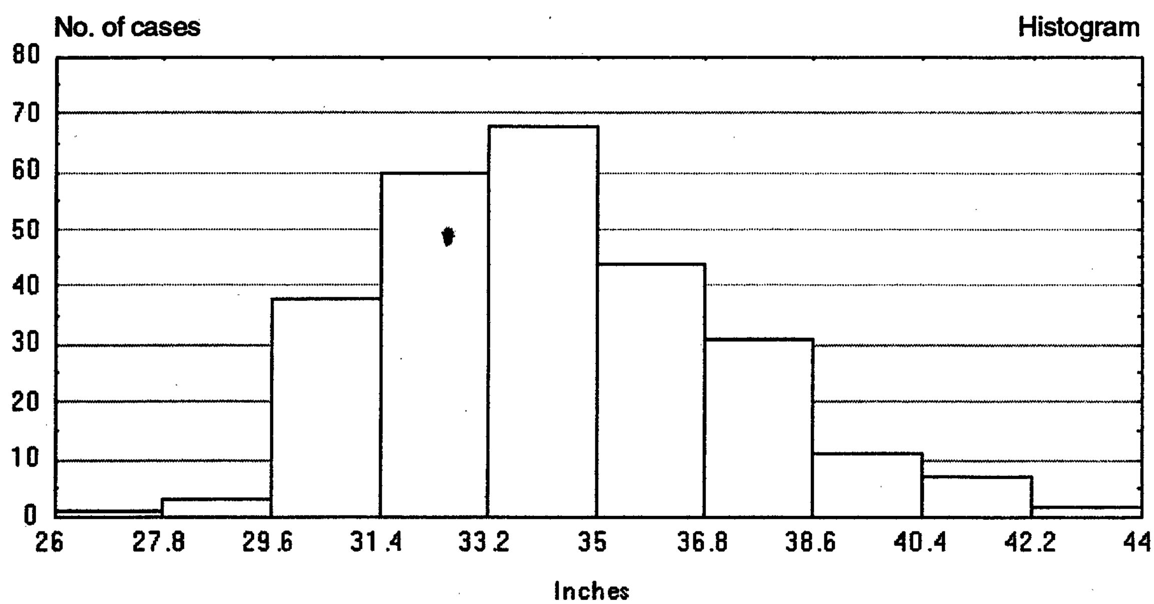

Figure 4. Distribution of Subject Waist (Omphalion)

Table 5. Distribution of Subject Test Location by Gender

	MALE		FEMALE	
LOCATION	Frequency	Percent	Frequency	Percent
Randolph AFB, Texas	59	22.3	2	40.0
Laughlin AFB, Texas	66	25.0	3	60.0
Nellis AFB, Nevada	54	20.5	0	0.0
Langley AFB, Virginia	20	7.6	0	0.0
Tyndall AFB, Florida	65	24.6	0	0.0
TOTAL	264	100.0	5	100.0

Table 6. Distribution of Subject Major Command by Gender

	MALE		FEMALE	
MAJOR COMMAND	Frequency	Percent	Frequency	Percent
Air Combat Command	74	28.0	0	0.0
Air Educ. & Training Command	190	72.0	5	100.0
TOTAL	264	100.0	5	100.0

Table 7. Distribution of Subject Race by Gender

	MALE		FEMALE	
RACE	Frequency	Percent	Frequency	Percent
White	260	98.1	5	100.0
Black	4	1.5	0	0.0
Asia	1	0.4	0	0.0
TOTAL	265	100.0	5	100.0

Table 8. Distribution of Subject Age by Gender

	MALE		FEMALE	
AGE	Frequency	Percent	Frequency	Percent
21	1	0.4	0	0.0
22	11	4.2	1	20.0
23	22	8.3	1	20.0
24	22	8.3	1	20.0
25	25	9.4	0	0.0
26	8	3.0	0	0.0
27	19	7.2	2	40.0
28	13	4.9	0	0.0
29	18	6.8	0	0.0
30	18	6.8	0	0.0
31	21	7.9	0	0.0
32	27	10.2	0	0.0
33	20	7.5	0	0.0
34	18	6.8	0	0.0
35	9	3.4	0	0.0
36	2	0.8	0	0.0
37	5	1.9	0	0.0
38	2	0.8	0	0.0
40	2	0.8	0	0.0
41	1	0.4	0	0.0
44	1	0.4	0	0.0
TOTAL	265	100.0	5	100.0

Table 9. Distribution of Subject Rank by Gender

	MALE		FEMALE	
RANK	Frequency	Percent	Frequency	Percent
Second Lieutenant	67	25.3	3	60.0
First Lieutenant	36	13.6	1	20.0
Captain	153	57.7	1	20.0
Major	8	3.0	0	0.0
Lieutenant Colonel	1	0.4	0	0.0
TOTAL	264	100.0	5	100.0

DATA COLLECTION METHODS

The fit test consisted of two components: 1) anthropometric measurements, and 2) fit assessment. Investigators recorded the fit assessment on a questionnaire-type data form due to the success of previous fit studies (Mellian et al., 1991, and Robinette et al., 1991) using questionnaires. The questionnaire provides a template for consistent recording of data, is easy to code for analysis, and allows the investigator to relate the fit difficulty to a particular area on both the item and the body.

The data collection team conducted two pre-test planning sessions to guide in the establishment of test procedures. Different anthropometric and questionnaire measuring instruments were tested, and the individual duties of the team members were examined.

The data collection team consisted of:

1. Briefer: greets subjects, explains the purpose of the study, gathers biographical data, and has the subjects read and sign the consent form.

2. Landmarker/Measurer: locates anthropometric landmarks and measures the subjects.

3. Recorder: assists the landmarker/measurer and records anthropometric data.

4. Evaluator: assesses and records the fit.

5. Fitter: selects the first size to be tested and assists subjects in selecting subsequent sizes.

To reduce excess repetitiveness in sizes, it is important to test the body size overlap in the sizes of each item. This was accomplished by testing each subject in "neighboring" sizes; i.e., testing the subject in the next smaller, larger, shorter, and longer sizes from the size initially selected as the "best fit" size. Testing neighboring sizes is necessary since, regardless of the care taken, the size initially chosen as the best fit may not be the best fit. Often there is enough fit overlap that sizes can be eliminated, and, in some instances, there is not enough overlap, so that some people in the center of the size range may not achieve a satisfactory fit. (Examples of these problems were described in the introduction.) Furthermore, testing neighboring sizes gives the fitter a larger margin for error, so the fitter can work more quickly and speed up the data collection process.

The fit assessment portion of the data collection consisted of the following steps: 1) fitter selects the estimated best fit size; 2) evaluator assesses this first size, both overall and by garment area region; 3) subject assesses the overall fit of the first size; 4) fitter selects the next neighboring size(s); 5) evaluator assesses each size neighboring the first size, both overall and by garment area region; 6) subject evaluates the overall fit of each neighboring size. Table 10 provides the guidelines for selecting neighboring sizes based on the best fit size.

Table 10. Best Fit and Adjacent Sizes

BEST FIT SIZE	SMALLER	LARGER	SHORTER	LONGER
1	-	4	-	2
2	-	5	1	3
3	-	6	2	-
4	1	7	-	5
5	2	8	4	6
6	3	9	5	-
7	4	-	-	8
8	5	-	7	9
9	6	-	8	-

Figure 5 is the anthropometry data sheet used in the fit study. Measurement descriptions for the anthropometry can be found in Appendix A. The recorder entered the anthropometry into a laptop computer as it was being collected, and a printed record of the data was also made at the end of the measuring session. The computer entry of anthropometry data served as a quality control system during data collection. The laptop software was set up to check the measurement

ATAGS Fit Evaluation

Subject Number:	______________________	Date:	____________________
Name:	______________________	Location:	____________________
Rank:	______________________	Race:	____________________
Age at Last Birthday:	______________________	Sex:	____________________
Date of Birth:	______________________	AF Specialty Code:	____________________
Place of Birth:	______________________	MAJCOM:	____________________
Reported Height:	______________________	Report Weight:	____________________

-----------------------------**DO NOT WRITE BELOW THIS LINE**------------------------------

Weight	______	Knee Height, mid	______
Stature	______	Calf Height	______
10th Rib Height, right	______	Buttock Circumference	______
Iliocristale Height, right	______	Buttock Circumference, max	______
Buttock Height	______	Buttock Height, max	______
10th Rib Height, left	______	Thigh Circumference	______
Iliocristale Height, left	______	Knee Circumference	______
Waist Height (pref)	______	Calf Circumference	______
Waist Height (omph)	______	Foot Circumference	______
Crotch Height	______	Foot Length	______
10th Rib Circumference	______	Foot Breadth	______
Waist Circumference (pref)	______	Hip Breadth, sitting	______
Waist Circumference (omph)	______		
Waist Circumference at Ilio	______		

Figure 5. Anthropometry Data Sheet

data to verify that it was within a reasonable range; anthropometric data from surveys were used for comparison. If the measurement appeared to be outside the range, the computer would sound a "beep." The measurer and recorder would then check the data to ensure that the measurement was taken and entered correctly.

The data sheet used to record the evaluations is shown in Figure 6. The investigators determined the garment area region to be evaluated during the pre-test planning sessions. These regions are shown in the left column of Figure 6. In some instances a garment area region is listed twice, but the type of response indicated is different. This allows the evaluator to record two different types of fit behavior; generally, a height-positioning type of fit behavior and a tightness-looseness type of fit behavior. The evaluator assessed each garment area region on a five-point scale. The dots between the words on the chart represent the ratings which fall between the levels on either side. For example, for the "lower leg" region: 1 = tight, 2 = between tight and OK, 3 = OK, 4 = between OK and loose, and 5 = loose.

The column marked "best fit" was usually the first size selected by the fitter. However, if a better fitting size was found during the evaluation, that size became the best fit size and the subsequent neighboring sizes were changed to conform to the new best fit size.

The evaluator recorded the overall ratings in the row marked "OVERALL" for both the evaluator, labeled as "evaluator," and for the subject, labeled as "subj." The rating scale is shown at the bottom of the Table for the OVERALL category. To assist in decisions regarding the level of the rating, each rating is defined as: excellent (1) = fits without any need for alterations; good (2) = fits with only minor alterations; fair (3) = might fit with major alterations; poor (4) = will have to be completely remade in order to fit; and unable to don (5). These definitions were repeated to the subjects, and the words were tacked on the wall for each subject to see while they made their assessments.

SUBJECT NUMBER _____

ATAGS	BEST FIT	SMALLER	LARGER	SHORTER	LONGER
SIZE	------	------	------	------	------
WAIST	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose
WAIST	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low
HIPS	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose
HIPS	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low
THIGH	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose
KNEE	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose
KNEE	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low
LOWER LEG	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose	Tight · OK · Loose
LEG LENGTH	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low	High · OK · Low
OVERALL	___ Evaluator ___ Subj	___ Evaluator ___ Subj	___ Evaluator ___ Subj	___ Evaluator ___ Subj	___ Evaluator ___ Subj

INVESTIGATOR COMMENTS: Size _____

SUBJECT COMMENTS: Size _____

Figure 6. Data Sheet Used to Record the Evaluations

MEN'S ANALYSIS

Methods

Fit evaluation seeks to answer questions such as, "Can any of the existing sizes be eliminated?" and "Are changes to the current sizing system needed to achieve a good quality fit?" Size selection issues involve such questions as, "What anthropometric dimensions are key to size selection?" or "What proportions of the population fall into what size ranges?"

Fit Evaluation

Guidelines for some similar studies done for AL/CFH in the past suggested *Multivariate Analysis of Variance (MANOVA)* as a way of exploring the quality of fit achieved by a garment sizing system. Typically, this would involve — as a first step, at least — testing for significant differences between size groups, based upon the different garment area fit ratings. While *MANOVA* does enjoy wider recognition and offer familiar measures of statistical confidence, there can be certain advantages to other methods, such as *Friedman Anova*, a nonparametric approach to repeated measures analysis. (Of course, both approaches could be used, but that's probably not practical.) Regardless of the comparative advantages or disadvantages, however, *MANOVA* could not be used in this case.

MANOVA requires an assumption that the area fit ratings come from a population of ratings that have a *Multivariate Normal Distribution.* While the reputed robustness of this procedure tends to encourage its application in situations where that assumption is not clearly met, in this case it was simply not justifiable. The garment area fit ratings used for the ATAGS fit study have only five possible values, and those values just don't capture enough variation in the fit evaluations, either to characterize a particular statistical distribution or to serve as a basis for the mathematical manipulations required by *MANOVA*. Out of 259 subjects (after allowing for missing data), a full 252 received overall best-fit ratings of "Excellent." The situation for many of the area fit ratings is similar. Clearly, the resolution of the rating values is just too coarse. This makes the mathematics of MANOVA simply impossible. In fact, the within-group covariance matrix is rendered singular.

The difficulties in using a parametric procedure such as *MANOVA* suggest that one of the rank-order *nonparametric* procedures might be more appropriate. In fact, *Friedman Anova* could accomplish essentially the same goal that *MANOVA* would in a parametric setting (Gibbons, 1985). However, even the use of *Friedman Anova* might be questioned here. While rank-order methods do not assume a particular statistical distribution, they do typically assume that the underlying variables are continuous. Again, the mere five values constituting the area fit ratings cause concern. They produce a great many tied ratings; and while tied ratings can be accommodated by rank-order methods, they are usually assumed to be small in number. In our case, there are far too many ties to be considered "small in number." It is not clear that too many ties will completely invalidate the procedure, but at the very least, they warrant a certain caution in our acceptance of the results.

We chose to use *Friedman Anova* for this analysis, and will discuss the details of its application in the appropriate section of this report.

Size Selection

Our primary tool for addressing the questions pertaining to size selection was *Discriminant Analysis*.[1] It allowed us to identify the best anthropometric dimensions for distinguishing between suit sizes and to define the desired sizing chart. It was also of some use in the fit evaluation process.

One of the special features of *Discriminant Analysis* that is offered by the statistical software used is a step-wise approach (both forward and backward). It is ideally suited for determining a specific number of key anthropometric dimensions.

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[1] ***Discriminant Analysis*** **is essentially an aspect of *MANOVA*, but the questions being asked by the researcher are typically somewhat different. For this reason, it is often implemented as a separate procedure in statistical packages in order to offer specialized features that are tailored more toward those different questions.**

Results

In the data analysis phase of the study, we were interested in answering several questions:

- Are changes to the current sizing system needed to achieve a good quality fit? If so, what are they?
- Can we eliminate any of the existing sizes? Do we need to design new sizes? Can we adjust existing sizes?
- How many sizes would be optimal for fitting the target population? What are they? How do they compare with existing sizes?

These questions required some evaluation criteria. What constitutes a good quality fit? What percentage of the population must be accommodated with an adequate fit? What adjustments to existing sizes would be practical (or impractical)? What constitutes an "optimal" situation for fitting the target population?

Anthropometry

A complete summary of anthropometric data, for male subjects only, is contained in Table 11. This data was used for determining the principal characteristics that discriminate between choice of size for the anti-G suit.

Quality of Current Fit

Table 12 indicates a need for most of the sizes. Since only one subject needed size 7, it can most likely be omitted from the sizing system.

Table 13 and Figure 7 show that the great majority of fits were rated "Excellent" by the evaluator. In terms of numbers, only 4 in 259 did not achieve a rating of at least "Good," and only 3 received "Good." Thus, 98.5% of the fits (255 in 259) had an acceptable rating of "Good" or "Excellent." If the ratings are accurate, then the current sizing system is probably adequate.[2]

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[2] A Figure of 98% has been suggested as a tentative criterion for adequate population coverage, while a design criterion for the sizing system was 96%. Since a 90% confidence interval on the ATAGS fit sample is simply a ± 0.1%, we will not be concerned explicitly with confidence intervals in the ensuing discussions.

Table 11. Male Summary Statistics for Anthropometric Data

Variable	N	Minimum	Maximum	Mean	Standard Deviation
Weight	265	123.46	249.12	173.31	21.51
Stature	265	64.37	77.28	69.99	2.44
10th Rib Height (Right)	265	39.61	50.04	44.80	1.94
Iliocristale Height (Right)	265	37.64	47.44	42.50	1.87
Buttock Height	264	31.65	40.59	35.78	1.77
10th Rib Height (Left)	265	40.24	49.96	44.70	1.92
Iliocristale Height (Left)	265	37.60	47.17	42.17	1.87
Waist Height (Pref)	265	36.14	45.75	40.37	1.83
Waist Height (Omph)	265	37.36	47.80	42.13	1.84
Crotch Height	265	28.54	37.28	32.58	1.59
10th Rib Circumference	265	26.73	40.20	33.34	2.49
Waist Circum (Pref)	265	26.57	42.56	34.00	2.68
Waist Circum (Omph)	265	26.77	42.87	34.30	2.87
Waist Circum (Ilio)	265	26.85	42.91	34.32	2.84
Knee Height (Mid)	265	16.73	23.43	19.68	1.02
Calf Height	265	11.65	15.94	13.64	0.84
Buttock Circumference	265	33.86	45.51	39.28	2.14
Buttock Circum (Max)	264	34.33	45.91	39.70	2.10
Buttock Height (Max)	265	30.55	40.04	34.66	1.79
Thigh Circumference	265	19.45	34.00	23.11	1.62
Knee Circumference	265	12.99	17.01	15.15	0.74
Calf Circumference	265	12.60	17.91	14.82	0.92
Foot Circumference	265	8.54	11.38	9.88	0.45
Foot Length	265	8.94	11.81	10.55	0.48
Foot Breadth	265	3.35	4.61	3.97	0.21
Hip Breadth, Sitting	265	12.83	17.48	14.82	0.87

Table 12. Male Suit Distribution of Best-Fit Size

Suit Size	Freq.	Percent	Cum. Freq.	Cum. Percent
1	30	11.36	30	11.36
2	58	21.97	88	33.33
3	13	4.92	101	38.26
4	18	6.82	119	45.08
5	76	28.79	195	73.86
6	35	13.26	230	87.12
7	1	.38	231	87.50
8	13	4.92	244	92.42
9	20	7.58	264	100.00

Table 13. Male Suit Cross-Tabs of Size Ratings

SIZE	EXCEL	GOOD	FAIR	POOR	Total
1	29	0	1	0	30
Column %	11.51%	0.00%	33.33%	0.00%	----
Row %	96.67%	0.00%	3.33%	0.00%	100.00%
Total %	11.20%	0.00%	0.39%	0.00%	11.58%
2	57	0	0	0	57
Column %	22.62%	0.00%	0.00%	0.00%	----
Row %	100.00%	0.00%	0.00%	0.00%	100.00%
Total %	22.01%	0.00%	0.00%	0.00%	22.01%
3	13	0	0	0	13
Column %	5.16%	0.00%	0.00%	0.00%	----
Row %	100.00%	0.00%	0.00%	0.00%	100.00%
Total %	5.02%	0.00%	0.00%	0.00%	5.02%
4	17	0	1	0	18
Column %	6.75%	0.00%	33.33%	0.00%	----
Row %	94.44%	0.00%	5.56%	0.00%	100.00%
Total %	6.56%	0.00%	0.39%	0.00%	6.95%
5	73	2	0	0	75
Column %	28.97%	66.67%	0.00%	0.00%	----
Row %	97.33%	2.67%	0.00%	0.00%	100.00%
Total %	28.19%	0.77%	0.00%	0.00%	28.96%
6	33	0	0	1	34
Column %	13.10%	0.00%	0.00%	100.00%	----
Row %	97.06%	0.00%	0.00%	2.94%	100.00%
Total %	12.74%	0.00%	0.00%	0.39%	13.13%
7	1	0	0	0	1
Column %	0.40%	0.00%	0.00%	0.00%	----
Row %	100.00%	0.00%	0.00%	0.00%	100.00%
Total %	0.39%	0.00%	0.00%	0.00%	0.39%
8	12	0	0	0	12
Column %	4.76%	0.00%	0.00%	0.00%	----
Row %	100.00%	0.00%	0.00%	0.00%	100.00%
Total %	4.63%	0.00%	0.00%	0.00%	4.63%
9	17	1	1	0	19
Column %	6.75%	33.33%	33.33%	0.00%	----
Row %	89.47%	5.26%	5.26%	0.00%	100.00%
Total %	6.56%	0.39%	0.39%	0.00%	7.34%
Col.Tot.	252	3	3	1	259
Column %	100.00%	100.00%	100.00%	100.00%	----
Row %	----	----	----	----	----
Total %	97.30%	1.16%	1.16%	0.39%	100.00%

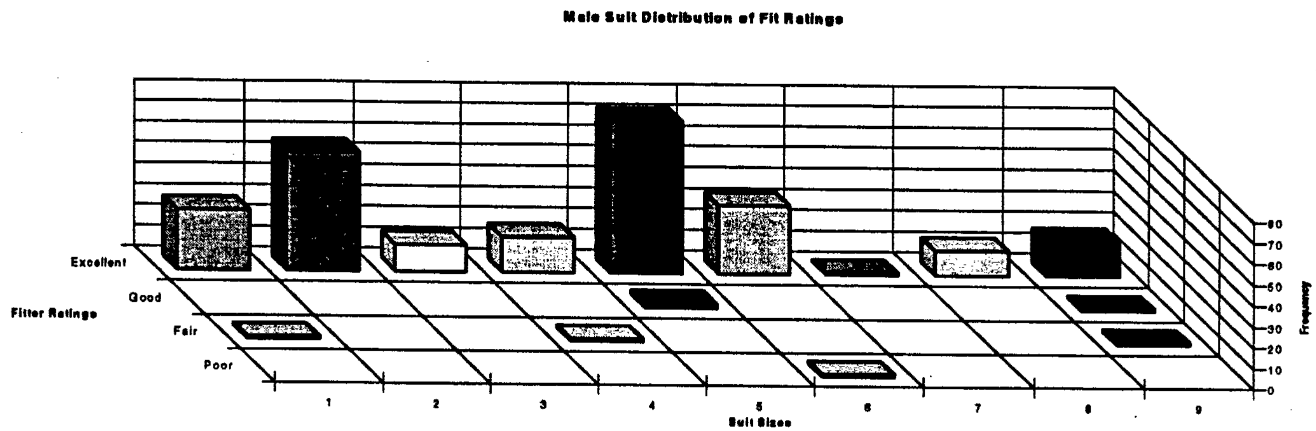

Figure 7. Male Suit Distribution of Fit Ratings

Can the quality of fit now achieved by the sizing system endure the elimination of one or more of the existing sizes? If not, can adjustments of the retained sizes compensate enough to restore adequate population coverage? These questions are addressed in the following sections.

Eliminating Existing Sizes

As already noted above, Size 7 is an obvious candidate for elimination. It was a best-fit size for only one of the subjects, and the neighboring Size 8 proved to be an excellent fit for that subject anyway. The next least-used suit sizes were 8 and 3, each used for 13 of the subjects (adding the one from Size 7 to Size 8). Size 8 has been identified by the Air Force as a size that they would like to eliminate if possible.

If we assume worst case — i.e., that none of the Size 8 personnel (including the former Size 7 we wanted to include here) could be fit satisfactorily with another size — then we would lose about 5% of the target population that we're now able to fit successfully. That would bring the total that are adequately fit down to about 93.4%. Is this high enough? Probably not. We have mentioned previously a desire for 98% population coverage. But how close can we get to 98% if we consider neighboring sizes for possible fits?

As it turns out, five of the Size 8's can be fit satisfactorily with Size 5; one of them with an "Excellent" fit, the other four with "Good." Two more of the Size 8's can be fit with Size 9, and one of those is also an "Excellent." That makes 7 out of 13, yielding a total test population coverage of about 96.1%. Of course, we're talking about just the test population here, but if the percentages of the target population that each size represents are faithfully represented, then we can generalize the 96.1% without too much concern. As mentioned earlier in a footnote, a 90% confidence level for the target population is simply ± 0.1%.

What about Size 3? This was the next least-used size. Size 3 actually fares better than Size 8, even though Size 8 is preferred for elimination. With Size 3, two of the subjects can be fit adequately with either Size 2 or 6; two more with Size 6, and four more of them with Size 2. That's a total of 8 out of 13. So if Size 3 were eliminated, but not Size 8, we would still have 96.5% of the population covered. If both Size 3 and Size 8 were eliminated, we would have only 94.2% of the population covered.

The situation for eliminating current sizes is summarized in the Table 14. Keep in mind, however, that these figures do not reflect the increased coverage we might gain with improvements to the suit, discussed in the next section. An accurate assessment of the effect of such improvements would require additional study, however.

Table 14. Effect of existing size elimination on population coverage

Eliminated Sizes	Compensating Sizes	Total Coverage
None	None	98.5%
7 Only	8	98.5%
7 / 8	5 / 9	96.1%
3 / 7	2 / 6	96.5%
3 / 7 / 8	2 / 5 / 6 / 9	94.2%

We can get an alternative picture of the effects of size elimination by applying the kind of *Discriminant Analysis* that we use later for identifying the key anthropometric dimensions. If we exclude the size to be eliminated from the *Discriminant Analysis*, we can use the results to reassign the eliminated cases and see which of the remaining sizes are most likely to be the best fits. Of course, we already know which sizes those will be — the neighboring sizes. But what we don't know is the relative proportions.

- Using this methodology on Size 8, we find that about half the Size 8's are reassigned to Size 9. The remainder are split between Sizes 5 and 6, but perhaps a little surprising is that Size 5 is slightly favored over Size 6.
- With Size 3, there are just a couple of subjects reassigned to Size 5, but the majority of them are evenly split between Sizes 2 and 6.
- We already know that Size 7 was fit well by the neighboring Size 8, but it might be nice to know that this procedure would predict that. It does.

While we could explore possibilities for eliminating some additional sizes, it is not really practical to do so. The percentages of the population represented by the other sizes are simply too large to be accommodated adequately by their neighboring sizes.

Having seen the degree of fit degradation resulting from the elimination of existing suit sizes, we need to explore the ways in which the current sizing system might be improved. First, we'll take a look at how the suits fit overall. Then we'll look at some individual sizes.

Opportunities For Improvement

Overall Improvements

Consider Figure 8. This shows the garment area ratings averaged across all sizes, both with the sizes weighted according to how many were placed in that size, and with the sizes all weighted equally. Since the plots are nearly identical, it is clear that no single size dominates the averages by having an inordinately large number of any particular rating. For subsequent comparisons, however, we will make use of the *equally weighted* sizes because they constitute a more meaningful conceptual basis for comparing the fit quality of one size against another. In any case, we can be fairly confident that any differences that might result from using the weighted sizes instead would be small.

We can see from Figure 9 that **Knee Height** is frequently too low. In contrast, the **Leg Length** proves to be a little short on the average. This would suggest that upper and lower leg proportions need adjustment. Examining these two ratings individually as a function of size in the next plot shows us that the shortcomings in these two dimensions do indeed span most of the sizes. **Leg Length** also shows a general trend toward going from too short on the smaller sizes to just slightly too long on the larger sizes. Size 7 is the only size in which both knees and leg length seem to be okay, but there was only one subject involved. Size 7 seems a likely candidate for elimination.

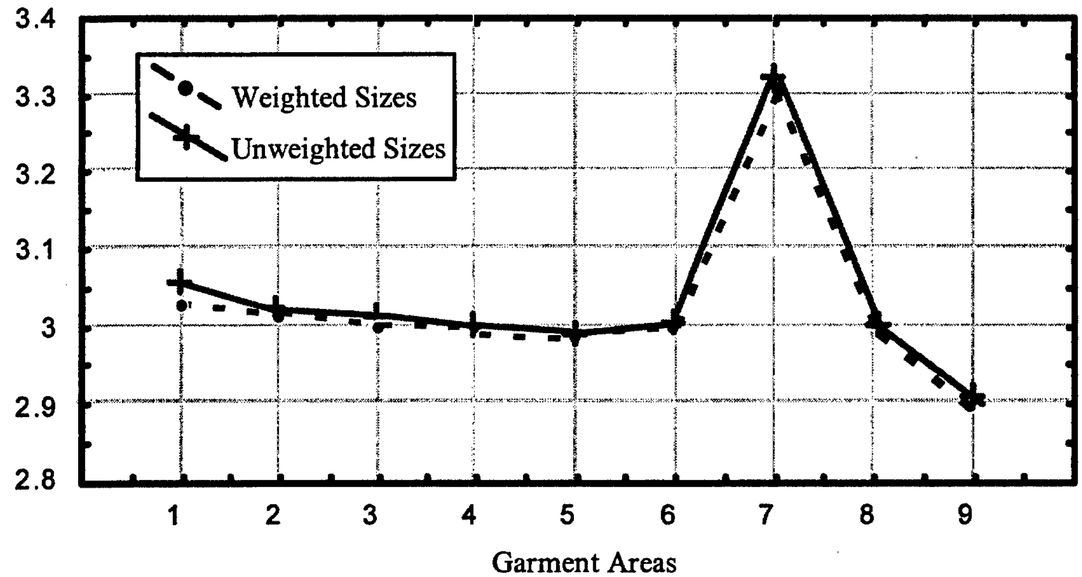

Figure 8. Average Garment Area Ratings

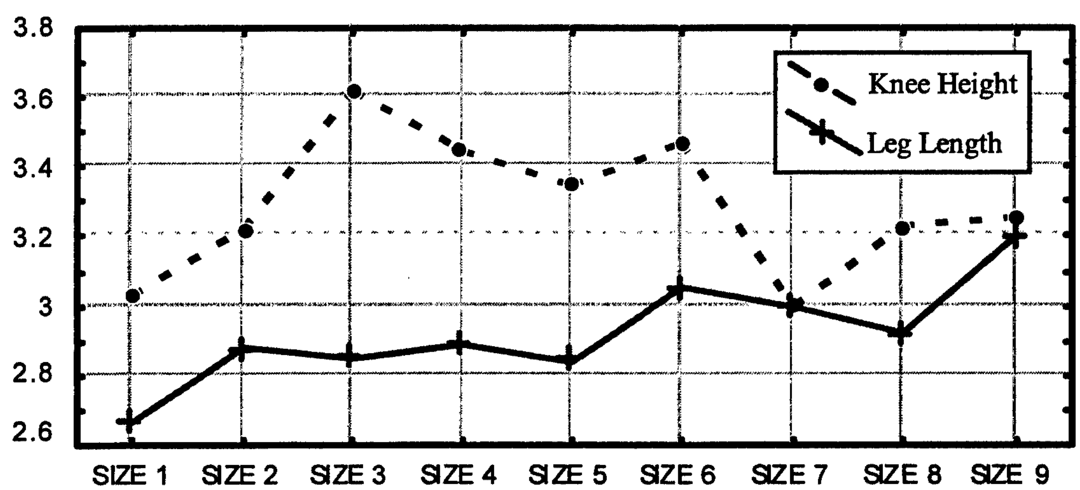

Figure 9. Average Ratings for Knee Height and Leg Length

Size-specific Improvements

In an effort to spot various short-comings in the quality of fit for the different sizes, we could easily imagine many dozens of different plots that might help us see what we're looking for. We can focus our efforts a little more effectively, though, by applying appropriate statistical procedures. Some guidelines for similar studies done in the past for AL/CFH have suggested *Multivariate Analysis of Variance (MANOVA)* as a way of exploring whether adjustments can be made to improve the fit of a garment. In earlier comments under **Methodology**, we saw several reasons why *MANOVA* could not be applied in this case, and *Friedman Anova* was mentioned as the alternative. However, even if *MANOVA* could be applied, there are still some reasons why *Friedman Anova* might be preferred.

Consider for a moment what a *MANOVA* (or equivalently, a *Discriminant Analysis*) would accomplish. First, it would provide a measure of confidence that the quality of fit across suit sizes is genuinely different. Second, it could tell us what garment area ratings tended to be the strongest source of those differences. With further investigation — maybe plotting the guilty area ratings across the different sizes — we could probably discover what sizes tended to be deficient in those ratings. Then we could compare the plots to see how many ratings any given size seemed to be deficient in, etc. And we'd still only know about the particular ratings highlighted by the *MANOVA*.[4] The point is that *MANOVA* would be focused on area ratings. What we really want is something focused on suit sizes — because the suit sizes are, after all, what we're really interested in.

The rank-order nonparametric procedure of *Friedman Anova* seems to address that need to some extent. It still gives us statistical indication that the quality of fit across suit sizes is genuinely different, just as *MANOVA* does; but then instead of focusing on the role played by garment area ratings in contributing to those differences, it provides detailed information on how the suit sizes themselves compare with one another. We can examine that information to see what suit sizes are most likely to be contributing to the differences, and then using those sizes as starting points, we can look for ways to make the sizes more uniform — i.e., uniformly good.

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[4] The plot of Knee Height and Leg Length in the previous section might very well be something a *MANOVA* would lead us to examine. But where do we go from there?

Viewing things from a slightly different perspective, we might ask whether all the area ratings "agree" on the quality of the fit. From this perspective, the issue seems to call for *Kendall's Coefficient of Concordance* (Gibbons, 1985). As it turns out, the *Coefficient of Concordance* and *Friedman Anova* are closely related; in fact, the problem setup is exactly the same. STATISTICA does both analyses as part of the same command. See Table 15.

Table 15. Friedman Anova and Kendall Coefficient of Concordance

Friedman Anova and Kendall Coef. of Concordance
Anova ^{2} (N = 9, df = 7) = 17.13433 $p < .01657$
Coef. of Concordance = .27197 Aver. rank r = .18097

Suit Size	Average Rank	Sum of Ranks	Average Rating	Rating Std. Dev.
Size 1	3.111111	28.00000	2.962963	.1123541
Size 2	3.000000	27.00000	3.001916	.0918194
Size 3	3.944444	35.50000	3.042735	.2213164
Size 4	5.277778	47.50000	3.055556	.1571349
Size 5	4.333333	39.00000	3.027908	.1337900
Size 6	5.722222	51.50000	3.071895	.1521978
Size 8	5.000000	45.00000	3.034188	.0869529
Size 9	5.611111	50.50000	3.088889	.1111805

This procedure seems to support the idea that there are indeed differences between the groups with regard to garment area fit ratings. Both the *Friedman Anova* p-value and the *Kendall Coefficient of Concordance* support that hypothesis. The *Coefficient of Concordance* would equal "1" for perfect uniformity among the ratings. Its low value of .27197 suggests strongly that the ratings are not uniform across sizes. Therefore, we need to look for the sources of these differences in order to identify any opportunities for improvement.

Here is where *Friedman Anova* offers an advantage. The entire output is oriented toward suit sizes, not area ratings. We can get an initial idea of where to look for differences by examining the "Average Rank" column.[5] It's evident that the Size 6 area ratings were, on the average, looser/longer than those of the other sizes, just slightly more than Size 9. Size 2, on the other hand, tended to be tighter/shorter than the other sizes, just slightly more than Size 1. If we compare the average area ratings for these individual sizes with the average ratings for the other sizes combined, we might be able to see more clearly just what the situation is. We'll look at the worst cases first — Sizes 6 and 2.

<u>Size 6</u>: It's clear from Figure 10 that Size 6 is generally looser in the hips and thighs than the other sizes; and even though the knees tend to be too low in virtually all the sizes, they're even lower for Size 6. Finally, while most of the other sizes are too short in leg length, Size 6 is just slightly too long. It would appear that Size 6 could use a little tightening in the hip and the thigh, maybe a little shortening in total leg length, and a more than proportionate shortening of the upper leg.

<u>Size 2</u>: Here we have just the opposite problem of Size 6 — Figure 11 shows that we're too <u>tight</u> in the hip and thigh. But while the knees still need to be raised, as in the other sizes, they need a somewhat smaller adjustment on the average. So the relative "high" is good in this case.

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[5] We could also look at the "Average Rating" column, but average rank is a better measure of how <u>consistently</u> Size 6 is looser/longer than the other sizes. Average rating, on the other hand, is influenced by how <u>much</u> Size 6 is looser/longer, regardless of how consistently. "How much" is not a concern at the present.

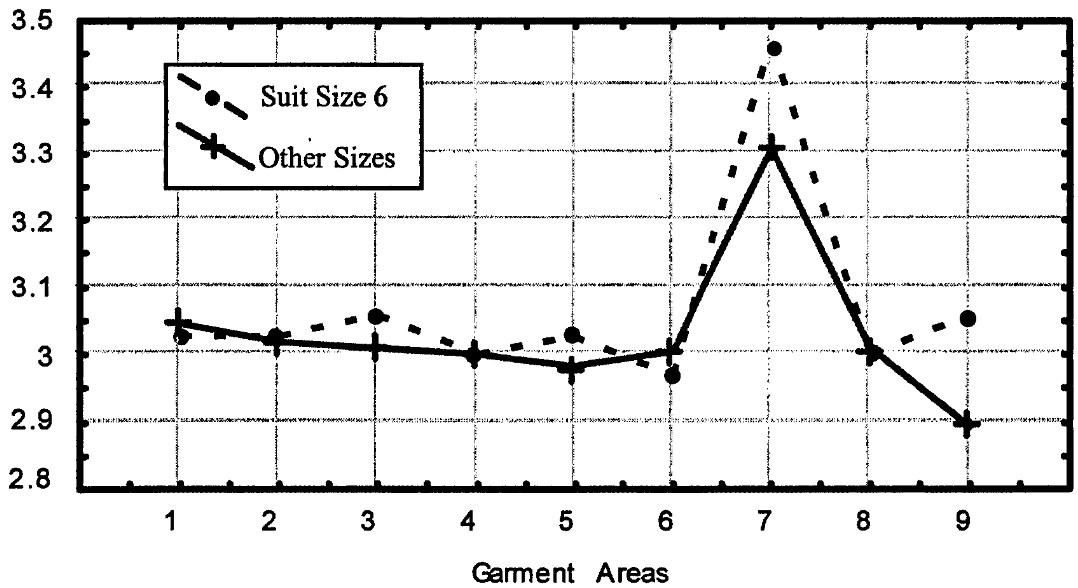

Figure 10. Size 6 Area Ratings vs Other Sizes

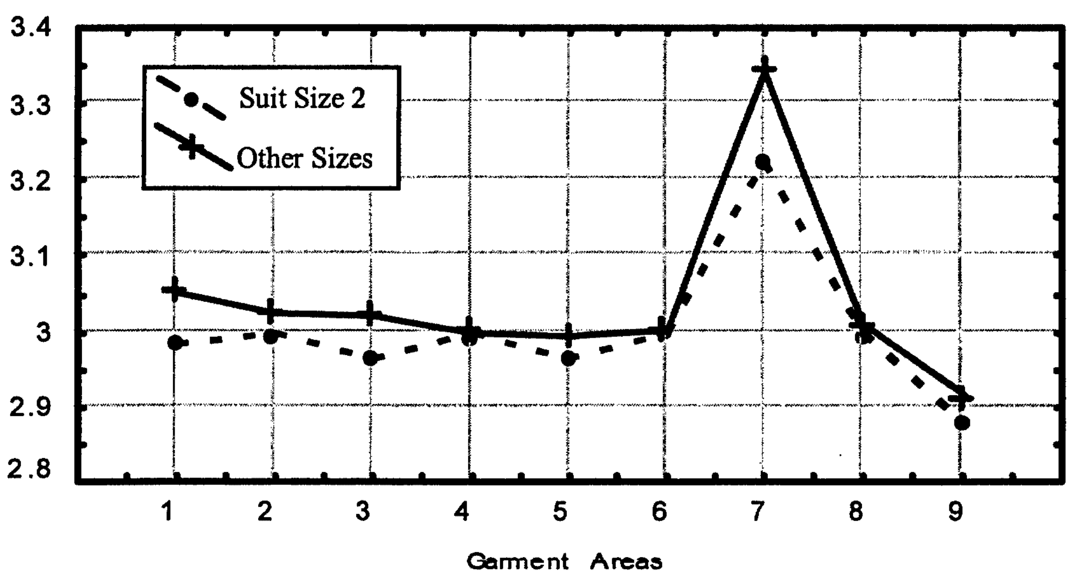

Figure 11. Size 2 Area Ratings vs Other Sizes

Although Sizes 6 and 2 are generally the worst fitting, Sizes 9 and 1 differed from them in average ranking by only about .1, whereas the other sizes tended to have rankings that differed somewhat more. Therefore, it seems worthwhile to look at Sizes 9 and 1, too.

Size 9: Several problems are evident in Figure 12. Size 9 is consistently too loose in the waist, and has a mild tendency to be too loose in the hips and knees as well. Moreover, while other sizes have too short a leg length, Size 9's is too long. In short, Size 9 is simply too big, although its knees tend not to be as low, relatively speaking, as the other sizes.

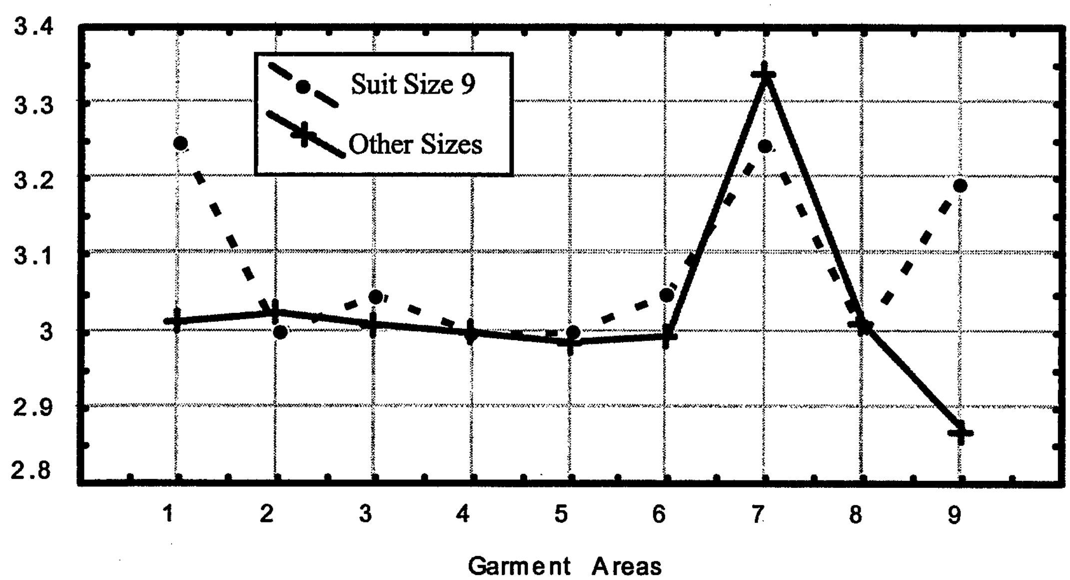

Figure 12. Size 9 Area Ratings vs Other Sizes

Size 1: Figure 13 shows that Size 1 is just slightly too loose in the waist, but leg length is conspicuously short. To its credit, Size 1 is the one size where knee height is almost right.

Adjustments to these four sizes should certainly improve the overall sizing system. Perhaps adjustment to Sizes 6 and 2 alone would be sufficient to bring noticeable results; but at least with these improvements, the degrading effects of size elimination would be offset somewhat.

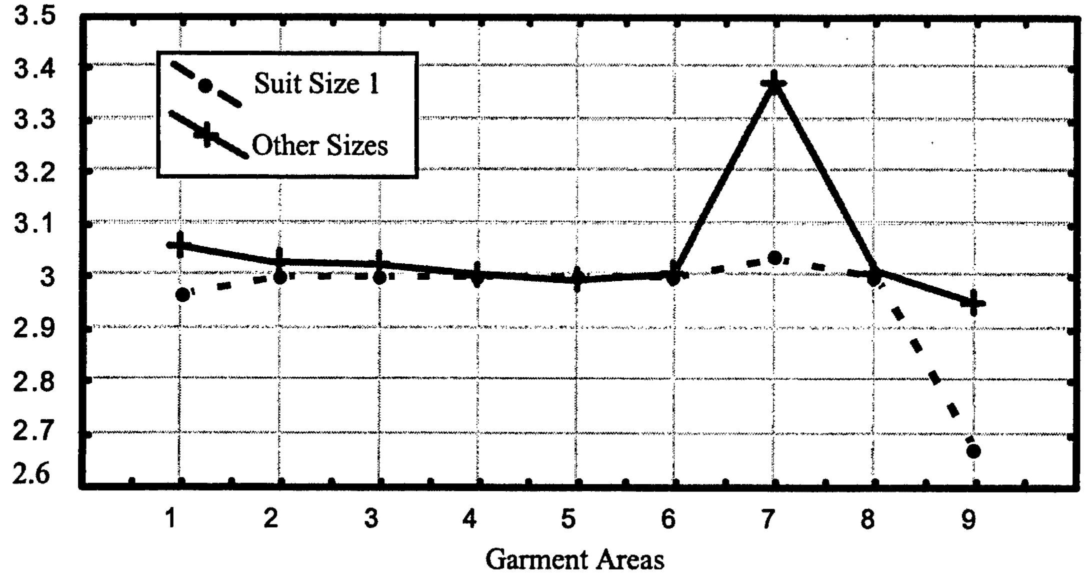

Figure 13. Size 1 Area Ratings vs Other Sizes

Size Selection

The objective of the size selection part of the analysis was twofold:

- Determine the key anthropometric dimensions for selecting the best fit suit size — i.e., those variables that best discriminate between sizes.
- Define a *Size Selection Chart*, with an accompanying *Tariff*, to serve as a guideline for purchasing the appropriate number of each size.

These two goals are discussed in the next two sections. First, we identify two key anthropometric dimensions that offer the best basis for specifying a *Size Selection Chart*. Then we use those dimensions, along with information on the relative proportion of population represented by each size group, to define the chart itself. The *Tariff* may seem at first simply to require us to write down the proportion of population represented by each size group in the test population; however, the situation is actually more complex than that.

Key Anthropometric Dimensions

The two anthropometric dimensions most indicative of best-fit size were obtained using a *Step-wise Discriminant Analysis* procedure. *Discriminant Analysis* applied to this situation determines an optimal linear combination of anthropometric variables that serves as a single-variable measure for performing an *Analysis of Variance (ANOVA)* on the anti-G suit size groups. The optimal linear combination of variables will be the one for which the *ANOVA* results in the highest significance level for differences among the suit sizes. This linear combination constitutes the *Discriminant Function.*

Actually, there is more than just one *Discriminant Function*. The number of discriminant functions will be either the number of anthropometric variables or one less than the number of suit sizes, whichever is smaller. Each function in turn consists of a linear combination of the anthropometric variables that is orthogonal to the previous ones. Each combination adds additional discriminating power.

Because we intend to define a *Size Selection Chart* based upon the key dimensions we find, we're really interested in only the two most discriminating variables. A chart using more than two variables would be difficult both to portray and to use. For this reason, we don't want to do a *Discriminant Analysis* on all of the anthropometric dimensions at once. That would produce linear combinations of <u>all</u> the variables. We would then somehow have to select the two most important variables from those combinations. It might be tempting to simply take the most significant linear combination and then select from that the two variables with the largest coefficients, but it would not be valid to do so.

Even setting a side the fact that we would be ignoring all but the first *Discriminant Function,* it's necessary to realize that the magnitude of a variable's coefficient may be no indication at all of its real contribution toward separating the suit sizes. In fact, a variable might very well have a large coefficient for no other reason than to <u>suppress</u> the amount of its own effect present in another variable (due to a correlation between the two variables). So even given a large coefficient in the discriminant function, a variable might have <u>no influence at all</u> in separating the suit size groups. Van de Geer offers a lucid example of the suppressor phenomenon (Van de Geer, 1971, 125-127).

Since we're really interested in having only two discriminant variables, a better approach is to perform a *Discriminant Analysis* that results in the linear combination of only two variables. This is done using a step-wise approach analogous to that used for step-wise regression. This step-wise approach will select the best possible pair of variables from the entire set. The documentation for most statistical packages will explain the procedures of step-wise regression, as will a common statistics textbook (Hays, 1991).

We performed both forward and backward step-wise procedures, including all variables, and were fortunate to have both procedures result in selecting the same two variables: **Waist Height (Omphalion)** and **Waist Circumference (Omphalion)**. The raw canonical coefficients for the variables that constitute the *Discriminant Functions* appear in Table 16.[6] As explained above, if the first function below were used as a single composite anthropometric variable, and then an *ANOVA* were done on the size groups using that variable, the result would provide a higher significance level than any other combination of two variables.[7]

Table 16. Two-variable discriminant functions

Variable	Function 1	Function 2
Waist Circ (Omph)	-0.56891	-0.4382
Waist Ht (Omph)	-0.77456	0.7436
Constant	52.13019	-16.3115
Relative Importance	78.72800%	21.2720%

Figure 14 indicates how successfully these functions are able to separate the size groups. Although the groups themselves are fairly distinct, a close look reveals definite overlap between

[6] No conclusions can be drawn from the relative size of the coefficients here, since they are not standardized. As it turns out, Waist makes a slightly greater contribution to Function 1 than Crotch Ht. does. In Function 2 the relative contributions are reversed. The first function always has the greatest effect.

[7] The alpha level for the discrimination provided by these two variables was about 0.00001.

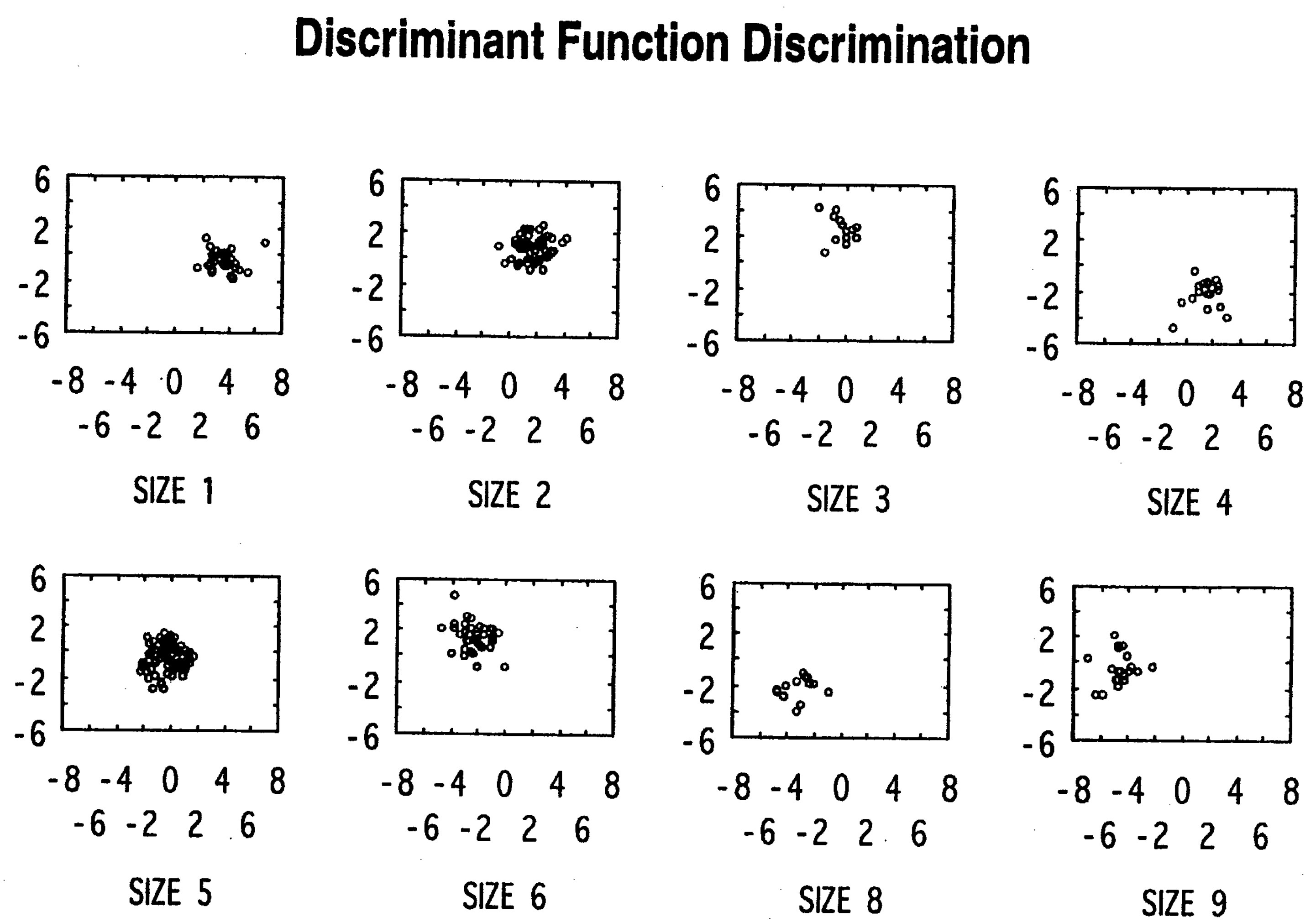

Figure 14. Discriminant Function Discrimination

the groups. All this means, of course, is that these variables do not accomplish 100% discrimination.

Size Classification & Sizing Chart

Once the *Discriminant Functions* are determined, they can be used to define a *Classification Function* for each of the suit size groups.[8] These *Classification Functions* are a measure of how "close" a given subject is to each size group, based upon the two key anthropometric dimensions. The higher the classification score for a given group, the "closer" the subject is to that group.

"Closeness" to a particular size group, however, is not the sole factor in determining which size suit is actually specified for a subject. We know, for example, that 28.8% of the tested subjects were best fit by a Size 5, and only 6.8% by a Size 4. If a subject is just slightly "closer" to Size 4 than to Size 5, based upon the *Classification Function*, is Size 4 necessarily the most likely best fit? No, it's not; because knowing that the overall probability of being a Size 5 is much greater than that of being a Size 4 tends to offset, to a certain degree, the prediction of greater "proximity" to Size 4. Bayesian techniques combine the "closeness" computed from the *Classification Function* with the knowledge of the percentage of subjects who end up with particular sizes (*prior probabilities*). This defines a set of new probabilities that each size will be the best fit for a particular subject. It is these *posterior probabilities* that define the sizing chart. The size indicated on the sizing chart is the most probable size for a given set of key dimensions, not the "closest." The sizing chart appears in Figure 15.

Applying the sizing chart to the subjects already tested can give us some idea of how well the key dimensions really discriminate. However, whatever results are achieved by doing this are necessarily optimistic. The procedure by which the classification of sizes is determined is unavoidably influenced by chance variation. Consequently, applying the classification functions to the same data used for deriving them can only reflect the best possible prediction accuracy. Accuracy when applied to new data will always be lower.

[8] Both *Discriminant Functions* are used to determine the *Classification Function* for each size group. Thus the total discriminating power of the two key variables is used for size classification.

Crotch Height	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0	42.5	43.0	43.5	44.0	44.5	45.0
50.0	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
49.5	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
49.0	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
48.5	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
48.0	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
47.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
47.0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
46.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
46.0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
45.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
45.0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
44.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
44.0	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
43.5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
43.0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
42.5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8
42.0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8
41.5	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8
41.0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8
40.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	5	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8
40.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8
39.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8
39.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8
38.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8
38.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8
37.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8
37.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8
36.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8
36.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8
35.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	8
35.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Figure 15. ATAGS Sizing Chart

With that in mind, we report the accuracy achieved in applying the results of this analysis to the ATAGS test data. The best-fit size was specified correctly for 85.2% of the subjects. The highest accuracy for a single group was 95% with Size 9 (19 out of 20); the lowest was 61.5% with Size 3 (8 out of 13). The most common size, Size 5, was selected with 89.5% accuracy (68 out of 76). The complete performance record for the two key dimensions of Crotch Height and Waist Circumference (Ilio) is shown in Table 17 below.[9]

Table 17. Classification Performance of Crotch Height and Waist Circumference

Percent Correct		Predicted Classification							
		1	2	3	4	5	6	8	9
86.66666	1	26	4	0	0	0	0	0	0
86.20689	2	3	50	0	0	5	0	0	0
61.53846	3	0	2	8	0	1	2	0	0
72.22222	4	1	0	0	13	3	0	1	0
89.47369	5	0	5	0	1	68	1	1	0
82.85714	6	0	0	1	0	4	29	0	1
84.61539	8	0	0	0	0	1	0	1	1
95.00000	9	0	0	0	0	1	0	0	19
85.17110	TOTAL	30	61	9	14	83	32	13	21

The 85.2% performance seems fairly good, considering that all 26 anthropometric variables together achieve an overall accuracy of only 86.3% — though the accuracy does vary noticeably less from size to size. This means that even if we could somehow use all 26 different anthropometric variables as a basis for size selection, 14% of the subjects would still have to try on more than one suit to get the best size (unless a particularly good fitter decides to ignore the

[9] An interesting fact was that step-wise analyses for three variables (which resulted in these same two variables plus one other that depended upon the step-wise direction) actually achieved less overall accuracy than these two alone (83.6%). This is only a statistical fluke, but it could not occur if the additional discriminating power of a third variable were substantial.

chart). The percentage would be less than this if some of the subjects also get a good fit in the "wrong" size.

Procurement Tariff

The number of each suit size needed to accommodate a given size population depends very much on how sure we want to be that we don't run out of any particular size. If we want a level of confidence greater than 50%, then a certain amount of safety stock is required. Each of the nine estimated percentages associated with the suit sizes has a different degree of uncertainty that depends upon both its own value and the number of personnel used for the fit test. Consequently, the amount of safety stock needed for any given size will be different, in general, from that needed for another size. Any procurement policy based upon the same percent of safety stock for every suit size will either be ineffective or will require an inordinately large safety stock in order to ensure that all sizes have sufficient quantities.

Table 18 provides three separate tariffs. The first simply indicates an estimated percentage for each suit size without regard to its uncertainty. These are the actual percentages observed in the fit data. They inherently result in a 50% chance that any given size will run out if no safety stock is purchased. The second tariff allows for uncertainty in the percentage estimate and takes into account the safety stock needed for each size individually to reduce the chances of a size shortage to 10% (i.e., 90% confidence). The new percentage for each suit size is the percentage of the new total ordered quantity, which is indicated by the overall percent safety stock needed. The third tariff reduces chances of a shortage in any given size to 5%[10]. Clearly, the amount of safety stock can be significant, depending upon the level of confidence desired. Concerns with this amount must be balanced against the cost of a shortage -- refill orders, lost time, etc.

[10] It is important to realize that these confidence levels pertain only to any given size -- not to all sizes at once. A confidence level for not running out of any sizes would require much larger purchases.

Table 18. ATAGS Procurement Tariff

Suit Size	Percent of Total Order		
	50% Conf. Exact Buy	**90% Confidence 22.4% Safety Stock**	**95% Confidence 37.0% Safety Stock**
Size 1	11.4%	11.6%	11.6%
Size 2	22.0%	20.4%	20.1%
Size 3	4.9%	5.9%	6.1%
Size 4	6.8%	7.6%	7.7%
Size 5	28.8%	25.9%	25.4%
Size 6	13.3%	13.2%	13.1%
Size 7	0.4%	1.3%	1.6%
Size 8	4.9%	5.9%	6.1%
Size 9	7.6%	8.3%	8.4%

Note that these tariffs do not attempt to accommodate any uncertainty in the number of personnel for whom the anti-G suits are being purchased. The tariffs assume this number to be known exactly. Any uncertainty in that number must be accommodated <u>in addition to</u> the uncertainties allowed for in these tariffs.

Summary and Recommendations

With all sizes included, 2% of the male population would need a custom suit, or they would have to fly without adequate g protection. This is not a large percentage, and it is not cost-effective to try to build sizes for all of the possible body size extremes. Therefore, we recommend that, in addition to the set of off-the-shelf suit sizes, a customized suit making process be developed to take care of the personnel who would not get an adequate fit in the available sizes. If a customizing process is used in conjunction with a set of off-the-shelf sizes, then the remaining question is, what percentage of the population should be accommodated in the set.

Since Size 7 adds no detectable amount of additional accommodation, it clearly should be eliminated from the set. Sizes 8 and 3 each add approximately 2% of additional and unique male population accommodation. Without just one of these sizes, 96% of the population would still be accommodated, and without both, 94%. These are good accommodation percentages, but the decision to eliminate them from the off-the-shelf set should take into account the cost and logistics of customizing versus the cost and logistics of producing, stocking, and maintaining the sized items.

WOMEN'S ANALYSIS

Background

The original Advanced Technology Anti-G Suit (ATAGS) was designed around a male population because it was envisioned to be a protective suit for combat aircraft, and women were not assigned to combat positions at that time. With the changing policies on women in combat, the need has developed to ensure that protective suits of this type also accommodate women.

It was evident from preliminary tests of the ATAGS on women that the large proportional differences between men and women in the waist and hip made the suits unacceptable for many women. For more than half the women in the preliminary testing, the suits could not be adjusted enough to stay in place for a fit evaluation. The preliminary testing was used only to establish the test procedures; the data was not recorded and the subjects were not pilots. However, it was immediately apparent that this type of anti-G suit requires sizes proportioned for a female form. The question then becomes: how should these sizes be proportioned for women? Women have long occupied non-combat military roles, and much research exists on women's sizing. In this study, research from past studies are examined and the data re-evaluated for application to the ATAGS suit. New data from recent fit tests are added to the analysis as well. The end results are recommendations for sizing anti-G suits for women.

The ATAGS sizing system specifies nine different sizes. These sizes are based upon two key anthropometric dimensions: Waist Circumference (Omphalion) and Waist Height (Omphalion). These measures are commonly taken and are very accurately repeated, which has made them popular with anthropometrists.

The evaluation of the fit of the suit for men revealed some particulars that provide important background for the female analysis. First, the men's analysis verified that the waist dimensions used to create ATAGS appear to be the best measures for size selection, or for categorizing the men who wear each size. Second, it was determined that Size 7 is unnecessary, fitting few (if any) men, and that Size 3 and Size 8 accommodate 2% or fewer men each. This seems to indicate that only six to eight sizes are actually needed to accommodate 95% or more of the male population. Since the female population has approximately the same multivariate variance/covariance as the male, with corrected proportioning the female population should require no more than 6 to 8 sizes. This could mean a total of 12 to 16 sizes for both men and women if no sizes can be shared. However, if some sizes can be shared, then fewer sizes will be needed.

Methods

There were two parts to this study: 1) a review of past research, and 2) testing on active duty female pilots.

The sizing data from the five female subjects were supplemented with fit results and anthropometric data from thousands of other women from other studies. The following past studies were examined and the data re-analyzed:

1. Male and female height/weight sizing studies for protective garments (Alexander et al., 1979, and Tebbetts et al., 1979)
2. Integrated sizing programs for U.S. Army men and women (Robinette et al., 1981)
3. Anthropometric Survey of U.S. Army Personnel Both Male and Female (Gordon et al., 1989)

New fit test data were also analyzed, including data from the recent fit tests of an anti-G suit, a flight suit, and a chemical protective coverall.

Five active-duty female pilots who had experience with anti-G suits were located and tested in the ATAGS using the same methods described in the previous section for men. Female pilots are rare, since the Stature and Sitting Height entry limits for pilots (greater than 64 inches in Stature and 34 inches in Sitting Height) allow only approximately 25% of Air Force women to qualify for flight training. Female pilots with anti-G suit experience are even more rare, since women have not been assigned to combat roles. It was felt, however, that experienced pilots would know better how the suits should fit. and could provide higher quality fit information about the suit than pilots without experience or women who were not pilots. Since these five women also met the entry restrictions for pilot training, they were taller than average for women and were more likely to achieve an acceptable fit in a flight suit designed for men. This is part of the region of size overlap. This information was used to identify fit information specific to this suit.

As there are little data on the fit of the ATAGS on females, a traditional statistical analysis as conducted on the male data was impossible. Therefore, another approach was used in this analysis involving three steps:

1. Determine expected relevant gender proportional differences.
2. Make inferences about ATAGS women based on other studies.
3. Make recommendations regarding a sizing system for the ATAGS that will accommodate women.

This analysis is complicated by potential policy changes that will permit the entry of a greater number of females into pilot training. Therefore, this analysis provides two sets of size recommendations. One set will pertain only to the population of females who meet the current entry requirements for pilot training. The other set will be relevant to the general military female population, in case policy changes do occur.

Results

In the seventies, Height and Weight sizing systems were proposed for flight suits and other protective gear for the Air Force. These systems used anthropometric survey data from 2,420 Air Force men and 1,906 Air Force women, as measured in 1967 and 1968, respectively. While not intended for use in comparing men and women, the Height/Weight sizing studies by Alexander et al. (1979) and Tebbetts et al. (1979) provide a rough estimate of the proportional differences between male and female dimensions of Air Force personnel. Figures 16 and 17 illustrate the eight size systems devised for men and women respectively in those studies. A comparison of the two charts indicates that the female Large-Long size and the male Small-Regular size are very similar. as are the female Extra-Large-Long and the male Medium-Regular.

WEIGHT (LB)

HEIGHT (IN)	120.0	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0	175.0	180.0	185.0	190.0	195.0	200.0	205.0	210.0	215.0	220.0	225.0	230.0	235.0	240.0	245.0	250.0	255.0	260.0
77.5														1		1													
77.0																			1										
76.5													1	1		1	1					1		1	1				
76.0																	1	1		2		1	1						
75.5												1	3	1	2	1	3	1	1	1		1			2				
75.0									1	1	2	1	1	3	2	2	2	1	5			1	1						
74.5								1		2		2	1	3	1	3	3		3	3	1	2		1					
74.0										1	3	1	4	5	2	4	10	4	9	5	1	3	1	1					
73.5					1		2	1	6	3		6	10	8	14	7	8	6	6	3	3	3			1				
73.0				1		2	2		1	4	10	15	5	9	4	1	7		9	4	4	3							
72.5							4	3	5	7	9	9	6	6	3	7	2	6	2	7	2		2						
72.0					2	4	5	5	7	12	9	10	7	9	11	8	10	7	3	2	5	1	1		2				
71.5					2	3	6	3	6	10	17	23	11	17	8	13	9	10	8	3	2	1		1					
71.0				1	5	3	7	10	13	16	8	21	26	15	15	13	8	4	4	1	2	1							
70.5			2	2	3	5	10	10	16	17	21	12	23	17	21	14	10	4	5	2	1								
70.0	1	1	1		3	5	13	16	19	14	24	11	34	22	13	13	10	4	3	2	2	1		2	1				
69.5		1	6	2	7	7	11	15	14	25	26	14	16	19	14	3	2	2	4		2								
69.0			1		7	12	10	8	13	13	17	22	21	14	4	5	9	2	1	1							1		
68.5		2		3	2	8	12	16	18	18	22	16	18	12	8	6	3	2		3				1	1				
68.0	2		2	9	6	11	19	12	15	32	21	9	14	6	5	3	2	2											
67.5		3	5	3	7	7	15	15	20	13	14	15	6	3	5	2		1	1										
67.0		1	4	2	5	10	5	9	13	13	13	6	12	3	3	1	1	1	1	1									
66.5			3	2	8		9	7	9	8	9	8	4	2	2	1	2												
66.0		2		3	5	6	5	5	11	9	4	1	4							1									
65.5			2	1	6		7	3	8	6	5	4	2	2															
65.0				2	2	4	4	3	3	2	1	1	2																
64.5	2		2	1		1	4	3	3		1	2																	
64.0			1	2	1	2	1	1	1		2																		
63.5		1	3	1				1																					
63.0	1	2	1					1																					
62.5			1																										
62.0									1																				
TOTAL	6	13	34	35	72	90	151	148	205	228	238	210	231	178	137	109	103	58	66	41	25	19	6	7	8	0	1	0	0

SI MI LL XLL SR MR LR XLR

Figure 16. Height/Weight Sizing Categories for USAF Men (from Alexander et al., 1979)

WEIGHT (LB)

HEIGHT (IN)	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0	175.0	180.0	185.0	190.0	195.0	200.0	TOTAL
72.0																			1						1
71.5																									0
71.0								1				1													2
70.5									1	1	1		1		2	1									7
70.0								1					2			1		1							5
69.5									2		1	1	5	1	1			1						1	13
69.0									1		2	3	1		1										8
68.5						1	1			3	7	3	4	1	1	1	2	1	1						26
68.0						1	1	1	4	2	6	1	6	4	2	2	1	1		1					33
67.5						1	1	4	3	7	8	5	4	3	6	3	2	1			2		1		51
67.0						2	1	3	8	6	3	11	10	8	4	4	2	2			1				65
66.5					1	1	6	9	6	10	11	14	12	10	2	2			1	2					87
66.0					2	2	6	4	16	16	12	13	10	14	5	5	1		2			1			109
65.5				1	4	4	7	16	13	17	19	12	13	7	4	1	4	2	1		1				126
65.0					1	2	9	13	13	27	17	15	12	9	5	1	1				1				123
64.5				2	3	11	11	12	20	19	19	9	17	7	6	2	1		1		1	1		1	143
64.0				1	7	10	18	21	24	29	15	13	10	4	2	2		1			1				158
63.5				4	8	9	20	28	25	10	13	9	7	1	2	1	1	1							148
63.0			2	5	7	20	23	30	22	19	12	8	2	1	2	1	1						1		156
62.5			1	3	13	11	20	16	22	17	10	4	1	2		2	1	1							124
62.0			2	6	10	18	20	21	21	11	8	5	3		4			1							130
61.5		2	6	5	16	9	19	11	17	10	8	9	1												113
61.0			3	10	14	20	17	13	5	7	6	8		2		1									100
60.5	1	1	1	7	9	7	8	7	8	3	1	2													55
60.0			2	3	6	13	9	8	4	3	2			1				1							52
59.5			2	10	8	6	5	2	4	4	1														42
59.0		1	1	1	1	1	4		2																11
58.5			1	1	2	1	1					1	1												8
58.0			1		1	2	2			1															7
57.5				1																					1
57.0				1																					1
TOTAL	1	4	22	61	113	152	209	221	241	231	181	142	122	72	49	30	17	14	7	3	7	2	2	2	1905

SI MI LL XLL SR MR LR XLR

Figure 17. Height/Weight Sizing Categories for USAF Women (from Tebbetts et al., 1979)

A comparison of the mean values within these sizes for four relevant measures is provided in Table 19 below. This gives a preliminary indication of the magnitude of the proportional differences.

Table 19. Comparison of Male and Female Sizes from Height/Weight Sizing Studies (inches)

Metric	Women		Men		Difference	
	LL	XLL	SR	MR	LL-SR	XLL-MR
Waist Circ.	28.0	30.1	31.1	34.0	-3.1	-3.9
Waist Ht.	41.7	42.7	38.8	39.7	+2.9	+3.0
Buttock Circ. Sit.	41.1	44.0	38.8	41.5	+2.6	+2.5
Thigh Circ.	23.0	24.7	21.1	22.9	+1.9	+1.8
Crotch Ht.	31.1	31.9	31.0	31.7	+0.1	+0.2

These comparisons indicate that women have smaller waists but larger hips than men of similar height and weight. For Waist Circumference (taken at the natural indent), the women are smaller, while for Buttock Circumference Sitting (the only hip measure which was measured the same on the men and the women in these studies), the women are larger. While Crotch Height measures are nearly identical for the sexes, the women have higher waists than the men. This combination of smaller and larger values is the crux of the problem.

This comparison is limited by the fact that the size categories, while similar, are not the same. In addition, Height and Weight, while having good "control" over other body measures in terms of size, do not appear to be the best "key" measures for an anti-G suit. The key measures used in an integrated, or unisex, sizing system devised for Army clothing in the eighties (Robinette et al., 1981) were Hip Circumference and Crotch Height. These are potentially good key measures for an ATAGS type anti-G suit. Furthermore, male and female data are presented for the exact same sizes in that report. Three of the size categories in the system had large numbers of both men and women: Medium-Long (ML), Large-Regular (LR) and Large-Long (LL). The male and female mean values for these sizes are compared below in Table 20.

Table 20. Comparison of Mean Values from Integrated Sizing System

Metric	Women			Men			Difference		
	ML	LR	LL	ML	LR	LL	MLΔ	LRΔ	LLΔ
Waist Circ.	27.0	29.4	29.2	31.2	34.7	34.3	-4.2	-5.3	-5.1
Waist Ht.	41.3	40.5	43.6	40.3	39.9	42.7	+1.0	+0.6	+0.9
Hip Circ.	36.5	39.5	39.5	36.5	39.5	39.5	0	0	0
Upper Thigh	21.5	23.6	23.5	21.5	23.6	23.4	0	0	+0.1
Crotch Ht.	31.5	30.5	33.5	31.5	30.5	33.5	0	0	0

This data indicates that if Hip Circumference and Crotch Height are the same, the women will have Waist Circumferences which are approximately 4 to 5 inches smaller and Waist Heights an inch larger on the average.

A more recent survey of the fit of the CSU-13B/P anti-G suits worn by 34 male and 28 female pilots showed similar results (Ripley et al., 1994). One problem is that the abdominal bladder is too long, extending over the ribs on many women and rendering the suit ineffective. Another problem is that 50% of the women and 24% of the men found the suit too loose in the waist. The fit of the suit is further complicated by the fact that 4% of the females found it too tight in the hips, while 12% of the men found it too loose in the hips. Again, these figures indicate that the women are proportioned differently than the men. Adjusting the suit to fit the men better would result in an even poorer fit for the women.

The data from the five women tested are presented in total in Appendix B. Of the five tested, two were rated by the expert fitter as having an excellent fit one had a good fit, and two did not get an acceptable fit in any of the nine sizes available. The two subjects with excellent fitter ratings rated the suit themselves as good. The one with a good fitter rating also rated the suit as good.

The sizes in which either a good or excellent fit were indicated were Sizes 1 and 2. Figure 18 is a bivariate plot of Waist Circumference (Omphalion) and Waist Height (Omphalion) (key dimensions for the men) for ATAGS males and females with the current sizing system. It

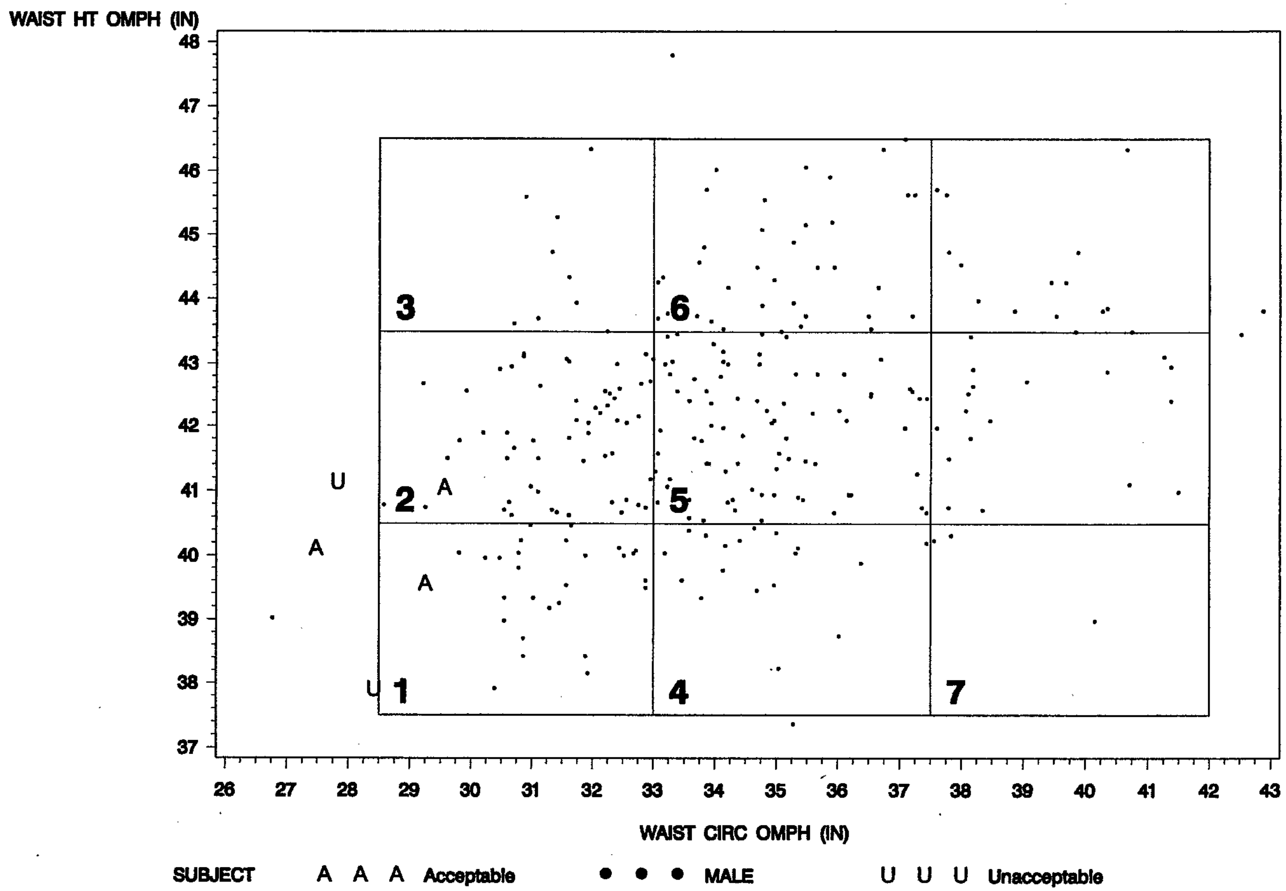

Figure 18. ATAGS Males Overlaid with ATAGS Females

illustrates the distribution of acceptable versus unacceptable fits for the ATAGS women. The women who got unacceptable fits did so because the fit of the suit's waist was so loose that the subject could put more than one fist down into the adjusted waist of the suit while wearing it, and the suit would not stay in place. Two of the three subjects with good or excellent ratings also had waists which were rated as loose and the third subject had a waist rated as too high, indicating the suit extended slightly over the bottom of her rib cage.

A small study consisting of nine women wearing the CSU-13B/P further enhanced understanding of the female fit problem (Robinette et al., 1995). Researchers found that the ATAGS fit women much better than the CSU-13B/P in the abdominal area, indicating that, while the ATAGS waist needs to be made smaller, the basic design of the ATAGS abdominal piece should not be changed.

Given what is known about the female ATAGS data, it is likely that gender-specific proportional differences similar to those described above would have been found had there been a larger number of female subjects. Figure 18 shows that the ATAGS females have smaller waists for any given Waist Height, verifying (at least for these data) what was expected. It also shows that these measures fall at the very lowest end of the range of Waist Circumferences for the males.

A sample of 71 female aircrew members was measured to characterize female aircrew as part of a flight suit study in 1992 (Crist et al., 1995). Figure 19 is a bivariate plot showing the distribution of Waist Height (Omphalion) and Waist Circumference (Omphalion) for these women versus the ATAGS females. The plot shows that the ATAGS females fall within the distribution of the flight suit study women for these measures, although at the small end of the circumference range.

The 1988 Army survey (Gordon et al., 1989) contains anthropometric data for 2,208 women and 1,774 men. The sample reflects the age/race profile of the U.S. Army as of June 1988. Figure 20 is a bivariate plot comparing the distributions of the flight suit study women and 1988 Army women data. The plot shows that the two distributions are quite similar even though the 1988 Army sample contains a larger number of heavier women (indicated by a greater number

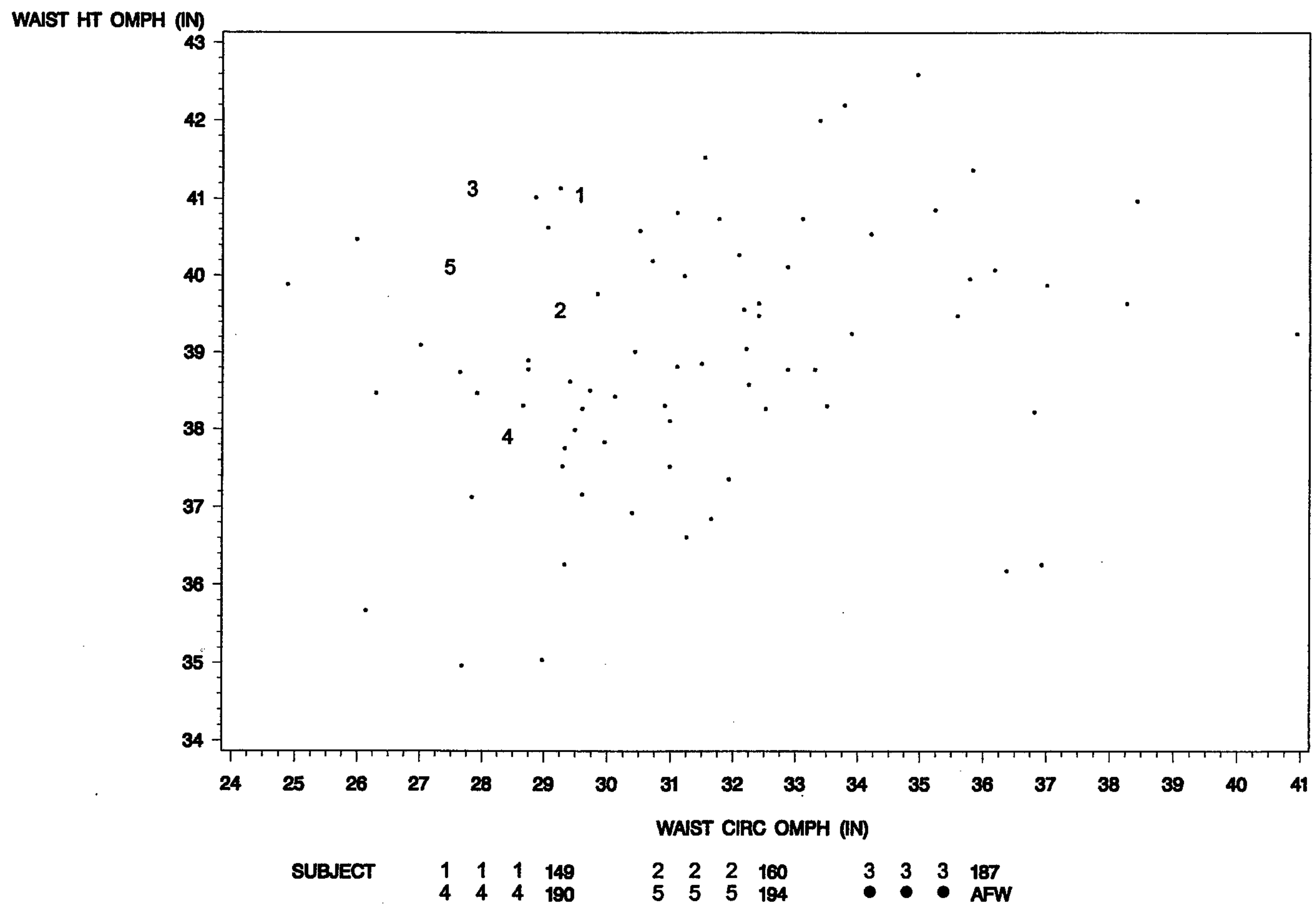

Figure 19. Air Force Flight Suit Women Overlaid with ATAGS Females

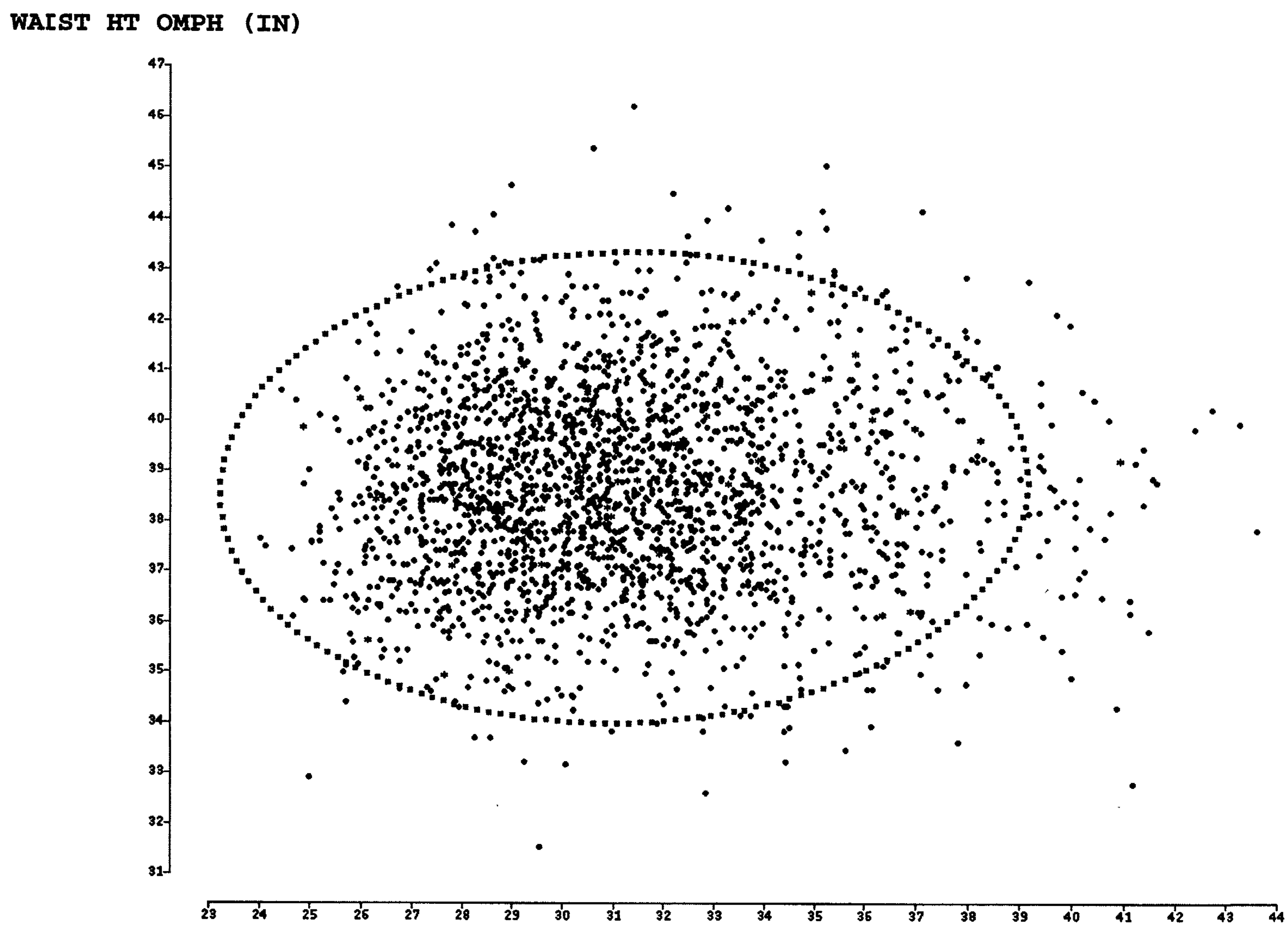

Figure 20. 1988 Army Females Overlaid with Air Force Flight Suit Females 95% Confidence Ellipse

of large Waist Circumferences). The Army sample was, therefore, considered suitable for estimation of the required number of sizes.

Size Selection

The expected differences in size and shape between the sexes suggest that men and women cannot share the current ATAGS sizes. Therefore, researchers devised a complete set of six sizes for women. Figure 21 is a bivariate plot of the 1992 Air Force flight suit women with ATAGS data. It shows the six sizes that are required to accommodate any military female. The sizing table appears in Table 21.

Table 21. Sizing Table for Women's Anti-G Suit

Size	Waist Circ	Waist Height
A	24 to 28.5 in	34.5 to 37.5 in
B	24 to 28.5 in	37.5 to 40.5 in
C	24 to 28.5 in	40.5 to 43.5 in
D	28.5 to 33 in	34.5 to 37.5 in
E	28.5 to 33 in	37.5 to 40.5 in
F	28.5 to 33 in	40.5 to 43.5 in

The intended patterns for the women's sizes are similar to the patterns for the men's sizes, except they are smaller in waist circumference and/or shorter in waist height. With this sizing scheme, the pattern for Size A would be exactly the same as that for men's Size 1, except 3 inches shorter in Waist Height and 4.5 inches smaller in Waist Circumference. The pattern for Size B would be exactly the same as that for men's Size 1, except 4.5 inches smaller in Waist Circumference. The pattern for Size C would be the same as that for men's Size 2, except 4.5

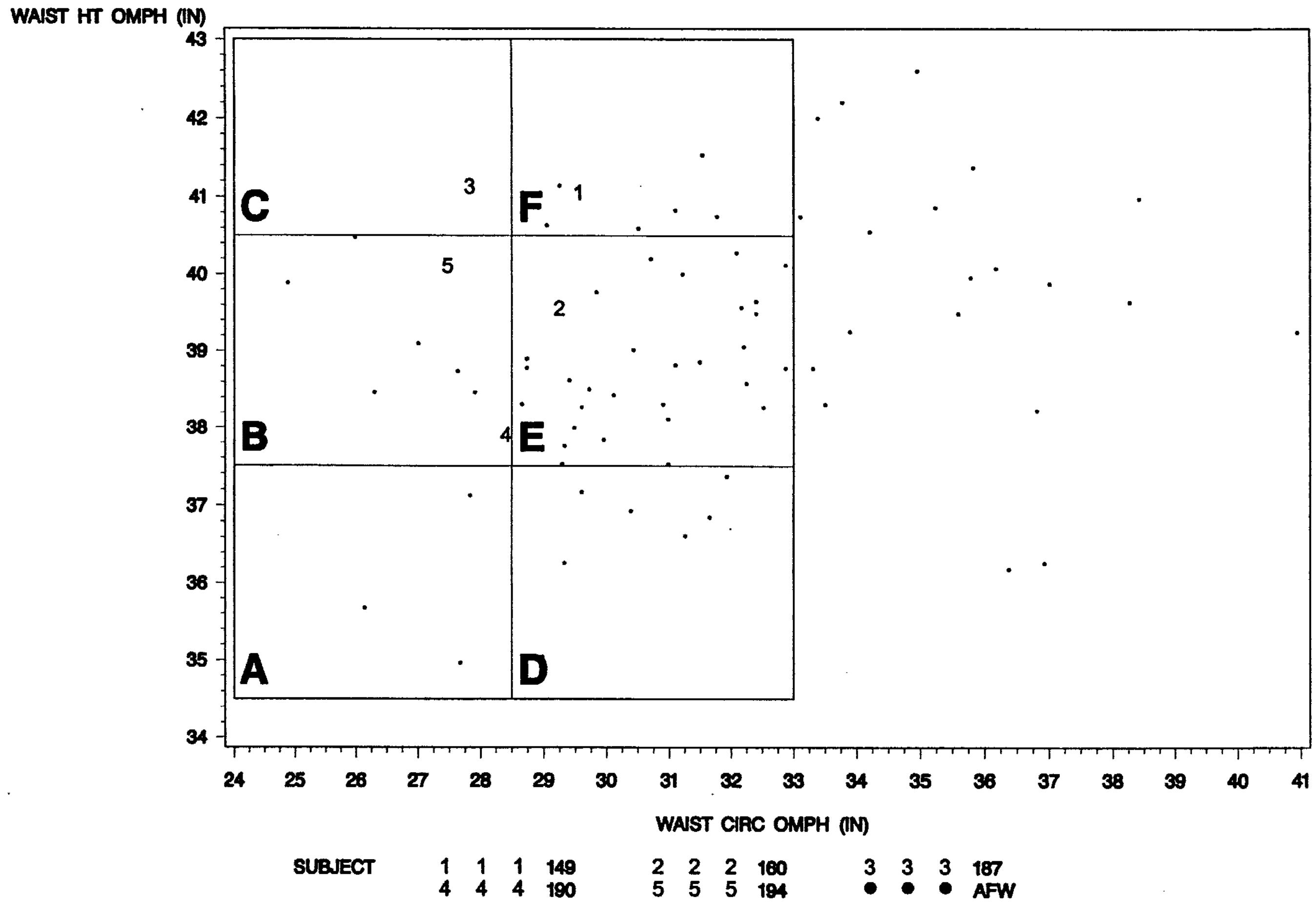

Figure 21. Air Force Flight Suit Women Overlaid with ATAGS Females Showing Expected Size Coverage

inches smaller in Waist Circumference. The pattern for Size D would be exactly the same as that for men's Size 1, except 3 inches shorter in Waist Height. The pattern for Size E would be exactly the same as that for men's Size 4, except 4.5 inches smaller in Waist Circumference. The pattern for Size F would be exactly the same as that for men's Size 5, except 4.5 inches smaller in Waist Circumference. A better fit in the waist-to-hip region could further be achieved by adding more lacing cord to the adjustment laces in the waist area of the women's sizes.

Figure 21 indicates that there are only a few female aircrew members with a waist height less than 37.5 inches. Therefore, of the six sizes recommended to accommodate any military female, only four are recommended to accommodate females who currently meet pilot training specifications. The four sizes are B, C, E, and F as listed in Table 21.

We estimated the number of each size to purchase using the 1988 Army survey. A procurement table for both sets of sizes is provided in Table 22.

Table 22. ATAGS Procurement Tariff for Women's Sizes

	Percent of Total Order	
Suit Size	Six Sizes	Four Sizes
Size A	8.5%	0.0%
Size B	16.2%	22.2%
Size C	3.6%	5.0%
Size D	18.2%	0.0%
Size E	41.4%	56.5%
Size F	12.0%	16.4%

Summary and Recommendations

Past studies have shown that women are not shaped the same as men. Women generally have smaller waists with larger hips than men. They also tend to have higher waists for any given crotch height. These physical differences, in consideration of the available fit data for women, indicate that men and women cannot share the current ATAGS sizes.

A complete set of six female-proportioned sizes are recommended in the event that pilot training entrance requirements are changed to permit entry of more females. Four of these sizes are needed to accommodate the current female pilot population. The patterns for the men's sizes can be used to create the patterns for the women's sizes. They will be the same, except that the women's sizes are smaller in Waist Circumference and/or shorter in Waist Height. It is also recommended that more lacing cord be added to the adjustment laces in the waist area of the women's sizes to allow a better fit in the waist-to-hip region.

The recommended women's sizes should be prototyped and fit tested, especially given the small amount of available fit data. A validation fit test will indicate whether the sizing system described in this report is adequate. If it is inadequate, further analysis should be conducted to determine whether more sizes are needed and/or if the patterns should be altered.

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APPENDIX A

DESCRIPTION OF ANTHROPOMETRIC MEASUREMENTS

Landmarks (marked landmarks only)

BUTTOCK POINT, right lateral and left lateral: Points on the thigh or hip at the level of the maximum protrusion of the right buttock. The subject stands erect with the head in the Frankfort plane. Stand at the right of the subject and sight the point of maximum protrusion of the right buttock. Set the landmark transfer rod to the height of this protrusion and mark the level on the right and left sides.

CALF POINT: A point on the side of the calf at the level of the maximum circumference of the right calf. The subject stands erect with the weight distributed equally on both feet. Stand behind the subject. Wrap a tape around the calf, crossing it at the back, and slide it up and down the calf to establish the maximum circumference of the calf. Be sure the tape is in a horizontal plane. Draw a short horizontal line along the bottom of the tape on the lateral side of the calf.

ILIOCRISTALE, RIGHT AND LEFT: The highest palpable point of the right iliac crest of the pelvis, one half the distance between the anterior superior iliac and posterior superior iliac spines. The subject stands in the anthropometric standing position. Stand in front of the subject. Use both hands to locate the anterior and posterior points of the iliac crests and note one half the distance between them. At this midpoint, use the tip of the finger to move upwards to the right side to locate the highest palpable point, and draw a short horizontal line through the landmark.

MIDPATELLA: The anterior point halfway between the top and bottom of the right patella (kneecap). The subject stands erect on a table with the knee relaxed. Stand in front of the subject. Grasp the kneecap with the forefinger on the suprapatella landmark and the thumb on the lower edge of the patella. Establish the midpoint by sight and draw a short horizontal line through the landmark.

TENTH RIB, RIGHT AND LEFT: The inferior point of the tenth rib (bottom of the rib cage). The subject stands erect. Stand in front of the subject and begin palpating the bottom of the rib cage on the right side. Work toward the front along the bottom of the tenth rib until you locate its lowest point. Draw a short horizontal line through the landmark.

WAIST (OMPHALION), right and left, anterior and posterior: Level of the center of the navel. The subject stands erect with the head in the Frankfort plane. Stand in front of the subject and locate the landmark by inspection. Draw a 4 cm horizontal line across omphalion, and using a landmark transfer rod, establish the other marks on the right and left sides, and on the back at the spine of the subject. The marks are drawn at the maximum point of quiet respiration.

WAIST (PREFERRED), right and left, anterior and posterior: The level at which the subject prefers his waist; an elastic band is placed around the waist. Instruct the subject to position the elastic band where a belt is normally worn. Make certain that the elastic does not constrict the waist. A mark is drawn at the level of the elastic on the center of the abdomen, on the right and left sides, and on the back at the spine. The marks will not necessarily be horizontal.

Dimensions (in alphabetical order)

BUTTOCK CIRCUMFERENCE: The horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock is measured with a tape. The subject stands erect on a table, looking straight ahead, with heels together and the weight equally distributed on both feet. Place the tape over both the buttock landmarks, making certain that the tape is horizontal.

BUTTOCK CIRCUMFERENCE, MAXIMUM: The maximum circumference of the hips is measured with a tape. The subject stands with the heels together and the hands folded near the waist, looking straight ahead. The measurer and recorder take this measurement as a team, with the measurer on the subject's left side and the recorder on the subject's right. The tape is placed around the subject's torso about 2 cm above the maximum protrusion of the buttock. The measurer and recorder use each other and a mirror in front of the subject to verify that the tape is horizontal at all times. The tape is moved inferiorly in approximately 1 cm intervals at the direction of the recorder. The recorder reads the tape noticing the increase in circumference. The tape is moved thus until the circumference no longer increases, and begins to decrease. Final adjustment of the tape is made to achieve the level of maximum circumference. Visual inspection of the subject will often suggest the approximate level where this will occur. At the level of the maximum circumference, the recorder will read the circumference from the tape. In some subjects, the maximum circumference will occur over a fairly broad area. In such cases, the level is defined as the lowest point of maximum circumference.

BUTTOCK HEIGHT: The vertical distance is measured between the floor and the most protrusive point of the right buttock. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet.

BUTTOCK HEIGHT, MAXIMUM: The vertical height of the maximum level of the hips. The level is determined when the Maximum Hip Circumference measurement is taken. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet.

CALF CIRCUMFERENCE: The maximum circumference of the lower leg measure perpendicular to its long axis. The subject stands with weight distributed equally on both feet.

CALF HEIGHT: The subject stands erect on a table with the heels together and the weight distributed equally on both feet. Stand at the right of the subject and use an anthropometer to measure the vertical distance between the standing surface and the drawn calf landmark on the right side of the leg.

CROTCH HEIGHT: The vertical distance between the standing surface and the crotch is measured with and anthropometer. Position the blade of the anthropometer so that the blunt end is facing the subject. Ask the subject to spread the legs, place the anthropometer to the right of the genitalia and then pull the anthropometer blade up until it is in firm contact with the crotch.

Then have the subject stand erect, looking straight ahead, with heels together and the weight distributed equally on both feet. Ask the subject to adjust the blade. Then exert additional upward pressure on the slide of the anthropometer to achieve firm and uniform placement. Read the instrument while it is still in place. The computer will add 1 cm to account for the width of the anthropometer blade.

FOOT BREADTH: The maximum horizontal distance across the right foot measured perpendicular to the long axis of the foot. The subject stands with the feet approximately 100 mm apart and with the weight distributed equally on both feet.

FOOT CIRCUMFERENCE: The circumference of the right foot measured with a tape passing over the widest points of the sides of the foot at the first joint of the big toe and the little toe. The subject stands with the feet approximately 100 mm apart and with the weight distributed equally on both feet.

FOOT LENGTH: The distance between the most protrusive point on the back of the right heel and the tip of the longest toe is measured parallel to the long axis of the foot. The subject stands erect with the weight distributed equally on both feet.

HIP BREADTH, SITTING: The subject assumes the anthropometric sitting position (sits erect on a flat surface with the knees bent 90 degrees and the thighs and feet parallel to one another). The maximum horizontal breadth across the hips or thighs is measured. Stand in front of the subject and use a beam caliper; exert only enough pressure to ensure that the caliper blades are touching the body.

ILIOCRISTALE HEIGHT, LEFT: The vertical distance is measured between the standing surface and the highest point (iliocristale) of the top of the left side of the pelvis in the midaxillary line. The subject stands erect looking straight ahead. The arms are relaxed at the sides and the heels are together with the weight distributed equally on both feet.

ILIOCRISTALE HEIGHT, RIGHT: The vertical distance is measured between the standing surface and the highest point (iliocristale) of the top of the right side of the pelvis in the midaxillary line. The subject stands erect looking straight ahead. The arms are relaxed at the sides and the heels are together with the weight distributed equally on both feet.

KNEE CIRCUMFERENCE: The horizontal circumference of the knee is measured at a level one-half the distance between the top and bottom of the patella (knee cap). The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet.

KNEE HEIGHT, MID: The subject stands erect on a table with the heels together and the weight distributed equally on both feet. Stand at the right of the subject and use an anthropometer to measure the vertical distance between the standing surface and the drawn midpatella landmark at the center of the knee.

STATURE: The vertical distance from a standing surface to the top of the head is measured with an anthropometer. The subject stands erect with the head in the Frankfort plane. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.

TENTH RIB CIRCUMFERENCE: The horizontal circumference of the torso is measured with the tape passing through the right and left tenth rib landmarks. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet.

TENTH RIB HEIGHT, LEFT: The vertical distance between the standing surface and the tenth rib landmark at the bottom of the left side of the rib cage is measured. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet. The shoulders and upper extremities are relaxed.

TENTH RIB HEIGHT, RIGHT: The vertical distance between the standing surface and the tenth rib landmark at the bottom of the right side of the rib cage is measured. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet. The shoulders and upper extremities are relaxed.

THIGH CIRCUMFERENCE: The circumference of the right thigh at its juncture with the buttock is measured with a tape. The measurement is made perpendicular to the long axis of the thigh. The subject stands erect on a table, looking straight ahead. The weight is distributed equally on both feet. The legs are spread apart just enough so that the thighs do not touch.

WAIST CIRCUMFERENCE (ILIOCRISTALE): The horizontal circumference of the waist is measured with the tape passing through the right and left iliocristale landmarks. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet. The subject must not pull in the stomach.

WAIST CIRCUMFERENCE (OMPHALION): The horizontal circumference of the waist at the level of the center of the navel (omphalion) is measured with a tape. The subject stands erect, looking straight ahead, with heels together and the weight equally distributed on both feet. The subject must not suck in the abdomen. Place the tape over the omphalion waist landmarks, making certain that the tape is horizontal. The measurement is made at the maximum point of quiet respiration.

WAIST CIRCUMFERENCE (PREFERRED): The circumference of the subject's preferred waist is measured with a tape. The subject stands erect, looking straight ahead, with heels together and the weight equally distributed on both feet. The subject must not suck in the abdomen. Place the tape around the subject's torso so that it lays on all the preferred waist landmarks. The tape may not be horizontal. Measure the circumference at the maximum point of quiet respiration.

WAIST HEIGHT (OMPHALION): The vertical distance between a standing surface and the center of the navel (omphalion) is measured with an anthropometer. The subject stands erect, looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders, upper extremities, and abdomen are relaxed. The measurement is made at the point of quiet respiration.

WAIST HEIGHT (PREFERRED): The vertical height of the subject's preferred waist is measured with an anthropometer. The subject stands erect with heels together, looking straight ahead and must be cautioned against sucking in the abdomen. The height is measured at the anterior preferred waist landmark.

WEIGHT: The weight of the subject is taken to the nearest half kilogram, while the subject stands erect on the platform of the scale, looking straight ahead. The weight should be equally distributed on both feet.

APPENDIX B

FEMALE ANTHROPOMETRIC, DEMOGRAPHIC, AND FIT DATA

Anthropometry

ATAGS anthropometric data is entered in millimeters and tenths of kilograms.

subjno	149	160	187	190	194
weight	615	570	605	570	620
stature	1763	1636	1755	1644	1658
10th rib height, right	1120	1059	1116	1044	1090
iliocristale height, right	1043	985	1066	987	1010
buttock height	881	813	869	821	848
10th rib height, left	1119	1058	1112	1041	1086
iliocristale height, left	1043	983	1055	985	989
waist height (pref)	1073	1018	1080	998	1035
waist height (omph)	1043	1005	1045	963	1019
crotch height	809	770	815	734	765
10th rib circumference	644	690	660	675	678
waist circ. (pref)	654	706	659	675	665
waist circ. (omph)	751	743	707	722	698
waist circ. at ilio	719	791	705	701	732
knee height, mid	486	430	478	448	459
calf height	328	292	327	302	320
buttock circ.	953	943	973	937	989
buttock circ., max	968	953	993	960	997
buttock height, max	831	804	834	773	785
thigh circumference	565	548	582	586	594
knee circumference	357	351	349	359	359
calf circumference	370	348	377	357	372
foot circumference	240	219	234	218	231
foot length	259	241	243	242	249
foot breadth	94	89	94	88	95
hip breadth, sitting	381	374	376	387	392

Demography

ATAGS demographic data are entered as follows:

subject number	149	160	187	190	194
rank	14	16	14	15	14
age at last birthday	23	27	27	24	22
month of birth	07	08	09	11	09
day of birth	29	01	28	24	01
year of birth	69	65	65	68	70
place of birth	09	27	10	07	07
reported height (inches)	70.00	65.00	70.00	66.00	65.00
month of test	05	05	06	06	06
day of test	19	21	17	17	18
year of test	93	93	93	93	93
test location	1	1	2	2	2
race	1	1	1	1	1
sex	2	2	2	2	2
air force specialty code	5	5	1	5	1
majcom	2	2	2	2	2
reported weight (lbs)	135.0	125.0	135.0	130.0	138.0

FIT DATA

ATAGS fit data are entered as follows:

subject number	149	160	187	190	194
best fit size	2	1	2	1	1
best fit waist	4	4	5	5	3
best fit waist height	3	3	.	.	5
best fit hip	3	2	.	.	3
best fit hip height	3	3	.	.	3
best fit thigh	3	3	.	.	3
best fit knee	3	3	.	.	3
best fit knee height	3	3	.	.	3
best fit lower leg	3	4	.	.	3
best fit leg length	3	3	.	.	3
best fit rating (fitter)	1	2	5	5	1
best fit rating (subject)	2	2	5	5	2
smaller neighboring size	.	.	.	.	.
smaller size waist	.	.	5	.	.
smaller size waist height	.	.	.	.	.
smaller size hip	.	.	.	.	.
smaller size hip height	.	.	.	.	.
smaller size thigh	.	.	.	.	.
smaller size knee	.	.	.	.	.
smaller size knee height	.	.	.	.	.
smaller size lower leg	.	.	.	.	.
smaller size leg length	.	.	.	.	.
smaller size rating (fitter)	.	.	.	.	.
smaller size rating (subject)	.	.	.	.	.
larger neighboring size	3	4	.	4	4
larger size waist	5	5	.	.	5

larger size waist height	.	.	.	.	.
larger size hip	.	.	.	.	.
larger size hip height	.	.	.	.	.
larger size thigh	.	.	.	.	.
larger size knee	.	.	.	.	.
larger size knee height	.	.	.	.	.
larger size lower leg	.	.	.	.	.
larger size leg length	.	.	.	.	.
larger size rating (fitter)	5	5	.	.	5
larger size rating (subject)	5	5	.	.	5
longer neighboring size	1	.	1	.	.
longer size waist	4	.	5	.	.
longer size waist height	5	.	.	.	.
longer size hip	3	.	.	.	.
longer size hip height	4	.	.	.	.
longer size thigh	3	.	.	.	.
longer size knee	3	.	.	.	.
longer size knee height	3	.	.	.	.
longer size lower leg	3	.	.	.	.
longer size leg length	2	.	.	.	.
longer size rating (fitter)	2	.	5	.	.
longer size rating (subject)	2	.	5	.	.
shorter neighboring size	3	2	.	2	2
shorter size waist	4	4	.	.	3
shorter size waist height	3	3	.	.	3
shorter size hip	4	2	.	.	3
shorter size hip height	3	3	.	.	3
shorter size thigh	3	3	.	.	3
shorter size knee	3	4	.	.	3
shorter size knee height	5	3	.	.	3
shorter size lower leg	4	3	.	.	3

shorter size leg length	5	5	.	.	5
shorter size rating (fitter)	3	3	.	.	1
shorter size rating (subject)	3	3	.	.	1